Effects of Confinement on Near-Failure Detonation Behavior in Vapor-Deposited HNS and HNAB Films

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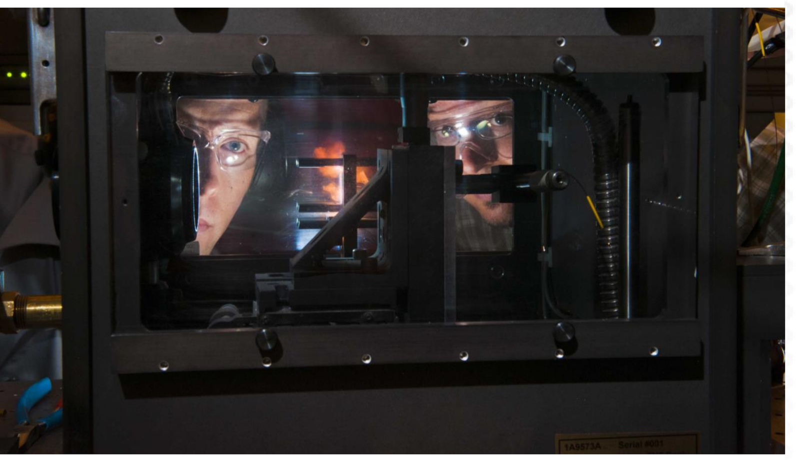

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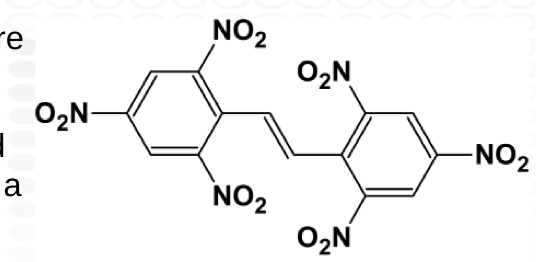
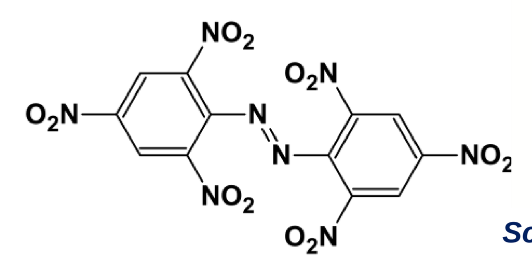
Detonation Confinement

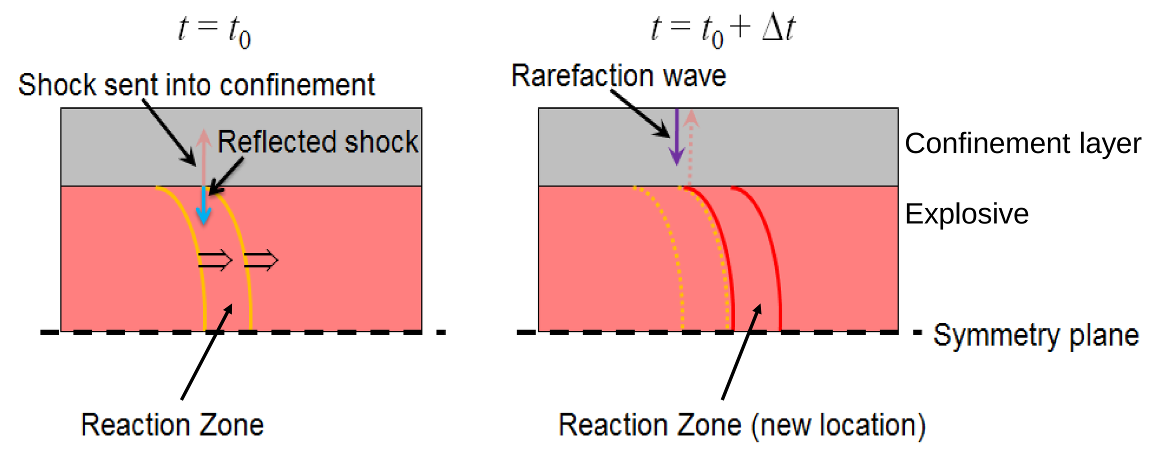
- Confining an explosive with a dense, inert material is known to have substantial effects on detonation velocity and failure geometry
- The amount of confinement needed and the magnitude of its effect are largely unknown
- Ramsay [8th Symposium (International) on Detonation, 1985] showed that confining an explosive with a low shock impedance material has a negligible effect on detonation failure geometry
- Physical vapor deposition allows for intimate contact between explosive and confinement layers as well as precise control over layer thicknesses
- We have performed experiments to determine minimum thickness of confinement necessary to behave as if it was effectively infinite in hexanitroazobenzene (HNAB) films confined with copper and in hexanitrostilbene (HNS) films confined with aluminum
- Studying effects of varying confinement thickness can provide information about detonation reaction kinetics



HNS

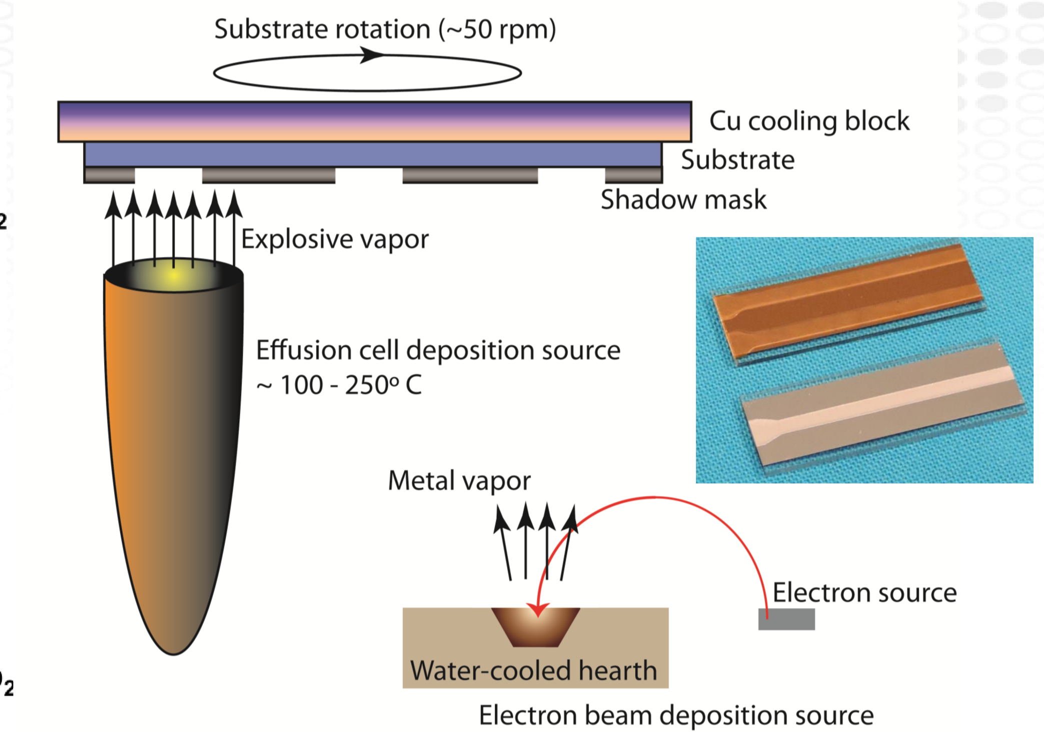


HNAB



Sketch depicting a detonation confined with a dense inert material. The effectively infinite confinement condition is reached when the confinement layer is thick enough that the detonation reaction zone can completely pass before a rarefaction can interact with it.

Physical Vapor Deposition Of Explosives



Schematic of the deposition system used to fabricate explosive films

- Deposition conducted in a vacuum chamber evacuated to ~ 10^{-6} Torr
- Fast deposition rate (~ 100 μm/hr) for HNAB
- Slower deposition rate (~ 5 μm/hr) for HNS
- Polycarbonate substrates used to minimize thermal expansion mismatch
- Shadow masks used to define deposition geometry
- Metal confinement layers deposited using electron beam evaporation
- Poor adhesion with copper required use of chromium adhesion layers

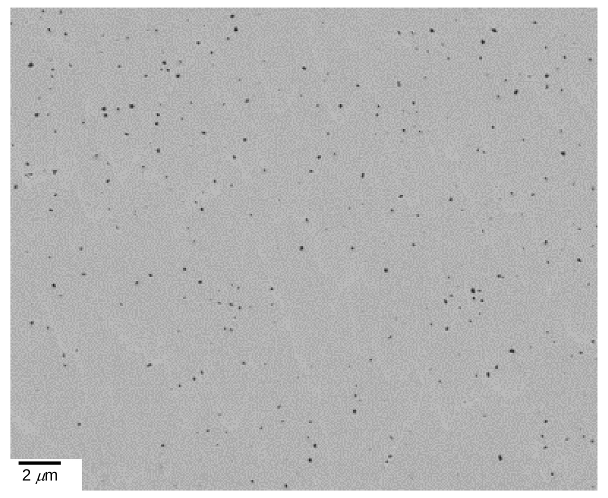
Microstructure

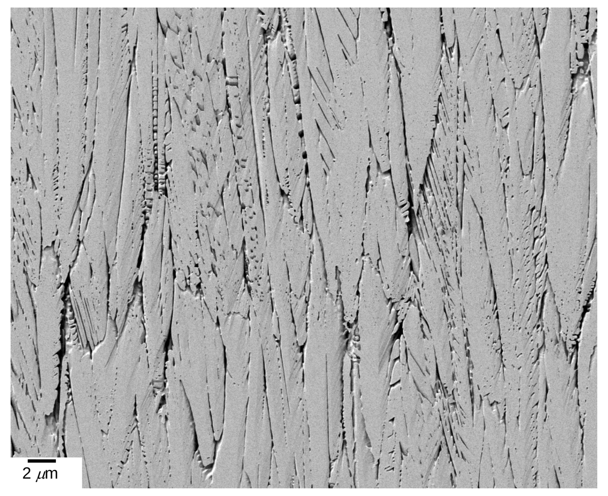
HNAB

- As-deposited: amorphous, fully dense
- Crystallizes over several weeks at ambient condition to HNAB-II structure (monoclinic $P2_1/a$)
- Equiaxed grains with sizes on the order of a few hundred nanometers
- Small amount of porosity develops during crystallization (~ 0.5 vol. %) with pore sizes of ~ 100 nm
- No preferred crystal orientation
- Low surface roughness (~ 50 nm)

HNS

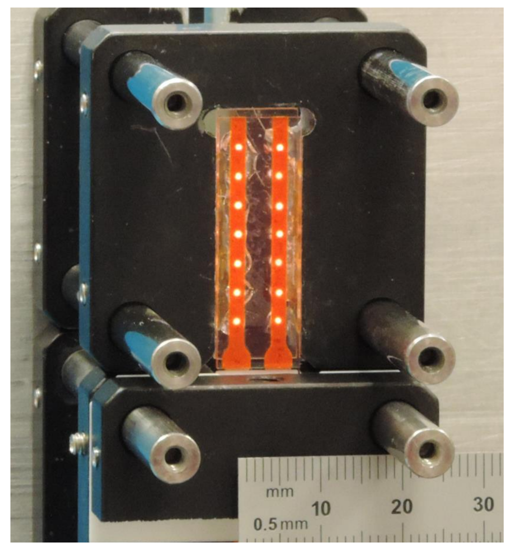
- As-deposited: polycrystalline (monoclinic $P2_1/c$)
- Columnar grains with sizes on the order of tens of microns in the growth direction and microns in the perpendicular directions
- Porosity ~10-15 vol.% (dependent on deposition conditions) – mixture of small, roughly equiaxed pores and large, elongated ones along column boundaries
- Strong preferred (200) out-of-plane crystal orientation
- Moderate surface roughness (~ 1 μm)



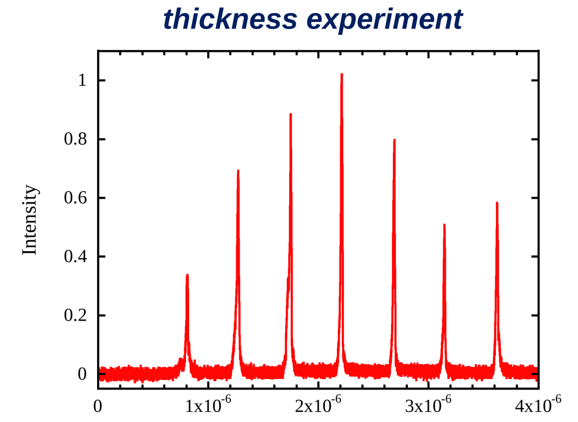


SEM images of ion-polished cross-sections of HNAB (left) and HNS (right) films

Detonation Testing

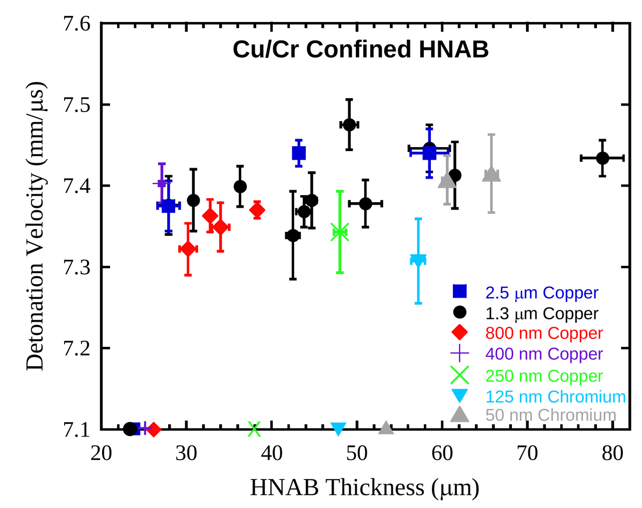


Detonation velocity/critical thickness experiment

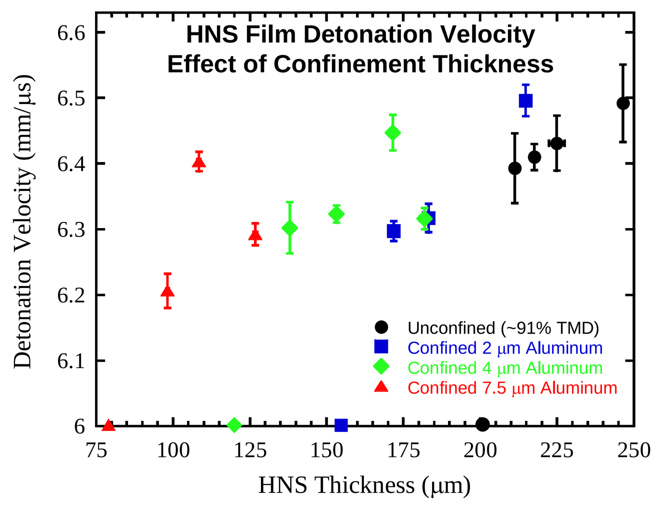


Example of oscilloscope data used to determine detonation velocity

- Detonation velocities measured using an array of fiber optics located along the length of each explosive line
  - ⇒ Fibers bundled in a SMA connector and fed into a silicon photodetector
  - ⇒ Fiber position plotted against time of arrival to determine detonation velocity

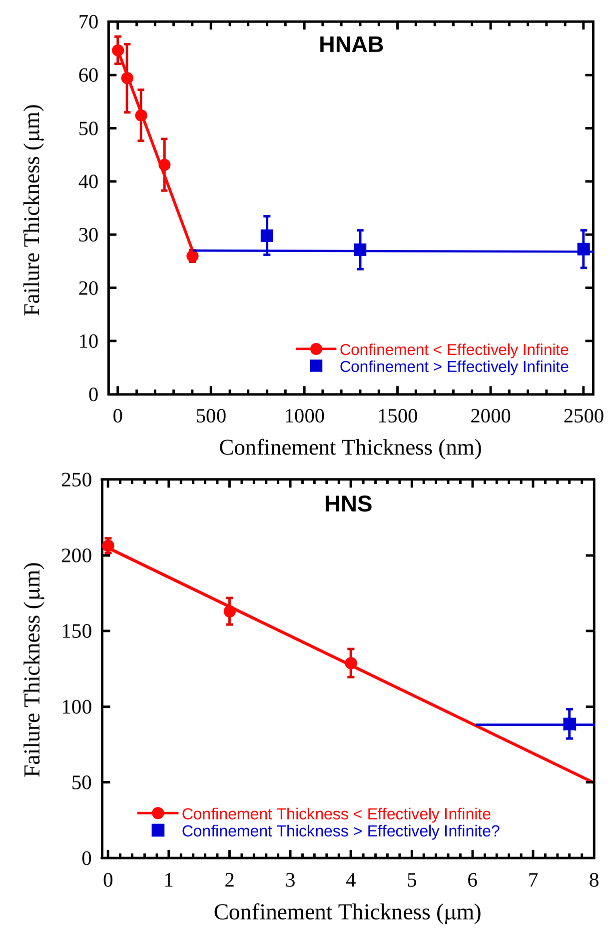


Detonation velocity vs. thickness for HNAB films with Cu/Cr confinement



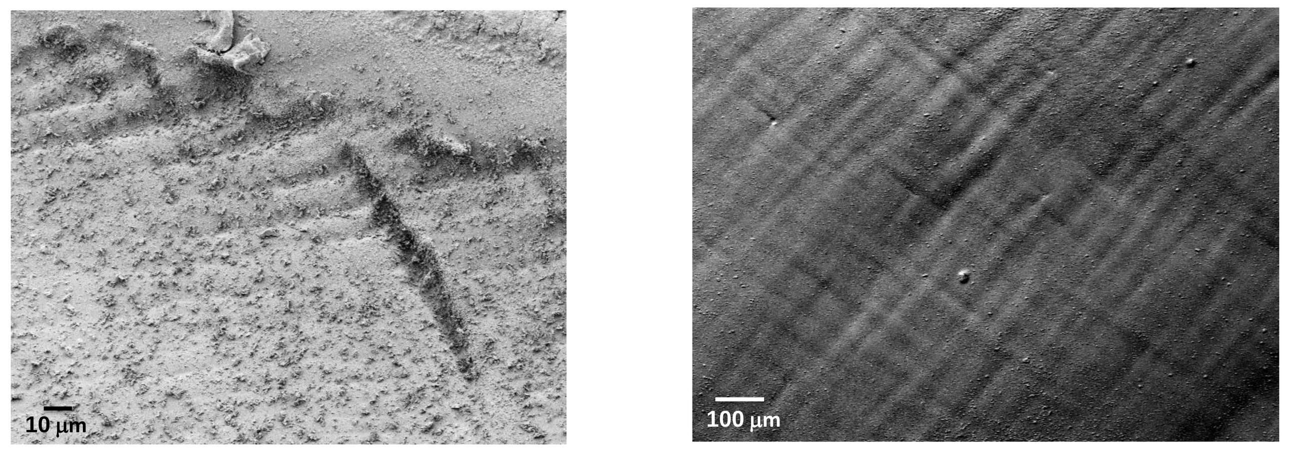
Detonation velocity vs. thickness for HNS films with and without Al confinement

- Detonation failure thickness in both HNAB and HNS decreases as confinement thickness increases until a threshold is reached (minimum effectively infinite confinement)
  - ⇒ HNAB failure thickness drops from ~ 65 μm unconfined to 27 μm at infinite confinement
  - ⇒ HNS failure thickness drops from ~ 205 μm unconfined to ~ 90 μm at thickest confinement tested
- No significant change in failure thickness when confinement thickness is increased beyond this point
- Can estimate reaction time/reaction zone length for the reactions that are driving the detonation from the confinement thickness at the minimum effectively infinite condition
  - ⇒ HNAB: 170 ps, 1.2 μm
  - ⇒ HNS: ~ 2 ns, 10 μm
- There is roughly an order of magnitude difference in detonation reaction kinetics between HNAB and HNS films – is this driven primarily by microstructure or inherent material properties?



Detonation failure thickness vs. confinement thickness for Cu/HNAB and Al/HNS

- Detonation failure thickness appears to vary linearly with confinement thickness while confinement is thinner than the minimum effectively infinite condition
  - ⇒ Suggests that 7.5 μm Al is effectively infinite confinement for HNS
  - ⇒ Indication that energy is released at a constant rate in the reaction zone?
- Ratio of "unconfined" to "infinitely" confined failure thickness is similar for HNAB and HNS, despite different confinement materials and explosive microstructures



SEM images of a dent tracks from near-failure detonation experiments in HNAB (left) and HNS (right) showing cross-hatching patterns

- Dent tracks in the polycarbonate substrates record cross-hatch patterns indicative of instabilities in the detonation front at near-failure conditions
- Cross-hatching only seen at the edges of tracks in HNAB, while it persists through the entire track in HNS
- "Cell size" in dent tracks from HNS films (~ 30 – 50 μm) is several times larger than seen in similar experiments with HNAB films (~ 5 – 10 μm)

Conclusions

- Detonation failure geometry appears to scale linearly with confinement thickness until effectively infinite confinement conditions are reached
- The minimum effectively infinite confinement condition can be used to indirectly measure detonation reaction kinetics
- HNAB films react approximately an order of magnitude faster than HNS films during detonation
- Ratio of unconfined failure thickness to infinitely confined failure thickness appears to be similar for HNAB and HNS films, despite different microstructures and confinement materials

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