Detonation Failure in Vapor-Deposited Hexanitroazobenzene (HNAB)

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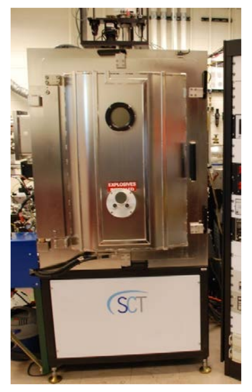

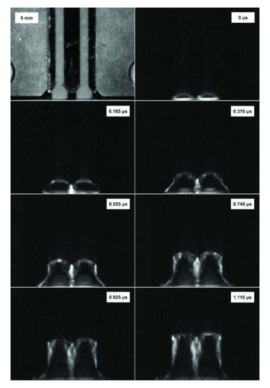

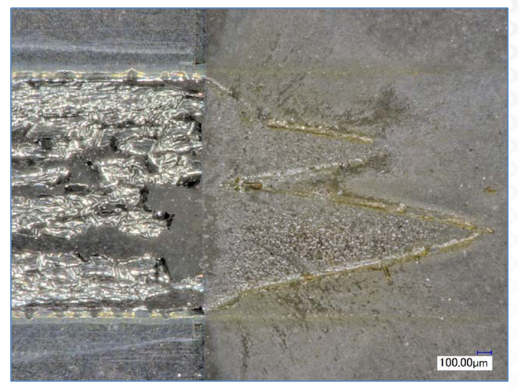

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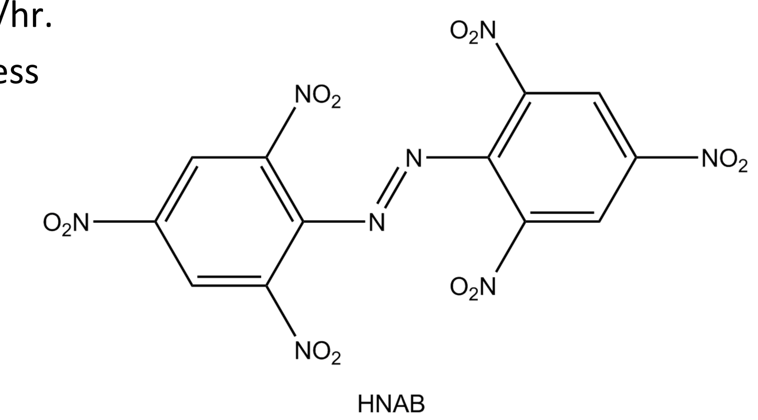
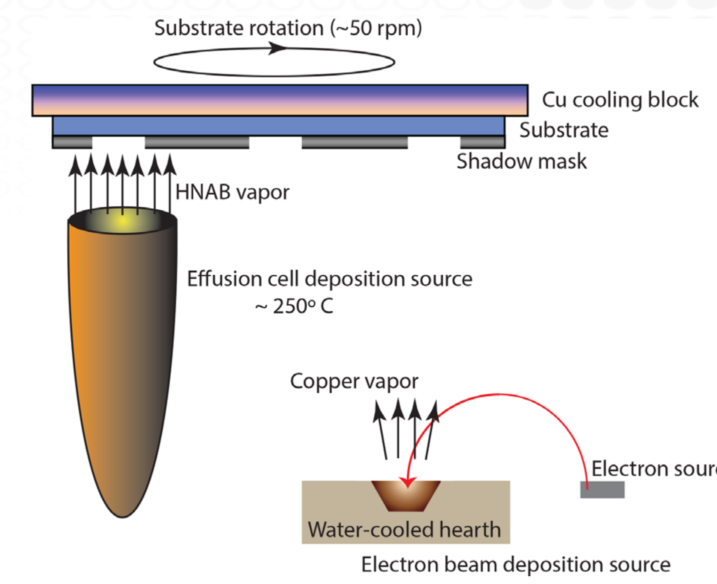
Physical Vapor Deposition Of Explosives

- Vapor deposition is a preparation technique that can be used to study the effect of microstructure on properties such as detonation failure
- HNAB (hexanitroazobenzene) is an explosive that can be vapor deposited and results in films with consistent microstructure and low surface roughness
- HNAB can be used as a model system to study detonation in a 2D film, which allows diagnostic access to a large area of the explosive
- Physical vapor deposition
  - 10^{-6} Torr background pressure, 70 – 280°C
  - Deposition rate range: 10 – 400 µm/hr.
  - Starting mass used to define thickness
  - Masks used to define film width
- HNAB
  - Melting point: 221°C
  - Density: 1.744 g/cm^3 (HNAB-II)
  - Detonation velocity: 7.42 mm/µs



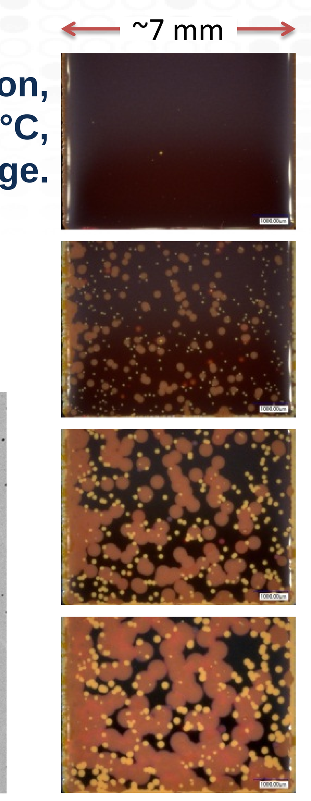


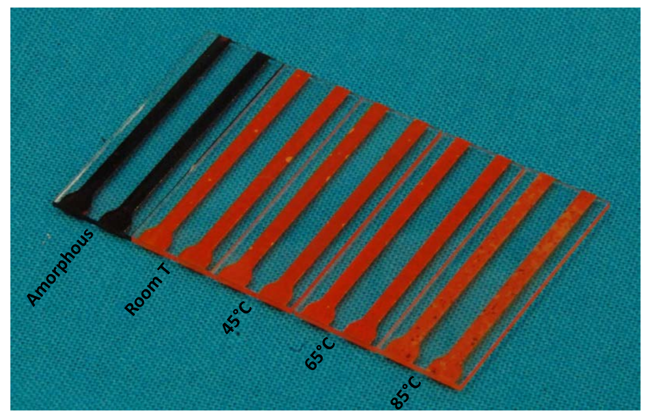
Physical vapor deposition of explosives is conducted using an effusion cell, with metal deposition occurring by electron beam evaporation as shown in this cartoon.

HNAB Crystallization and Microstructure

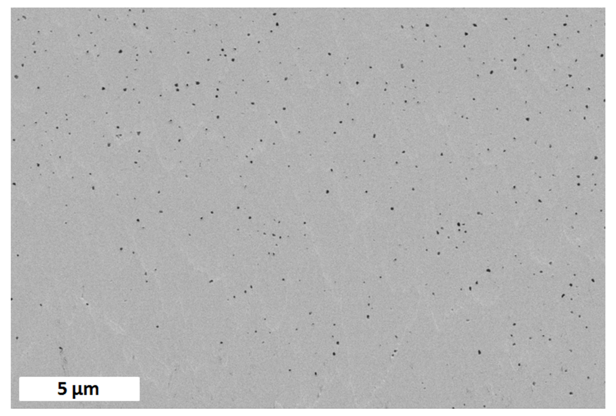
- Amorphous HNAB crystallizes over time into HNAB-II and a yet undetermined yellow phase
- Higher temperatures increase the rate of crystallization
- HNAB crystallized at room temperature has well-distributed pores, ~100 nm
- HNAB crystallizes to a density of ~99.3%

HNAB crystallization, time-lapse 65 °C, 24 min./image.





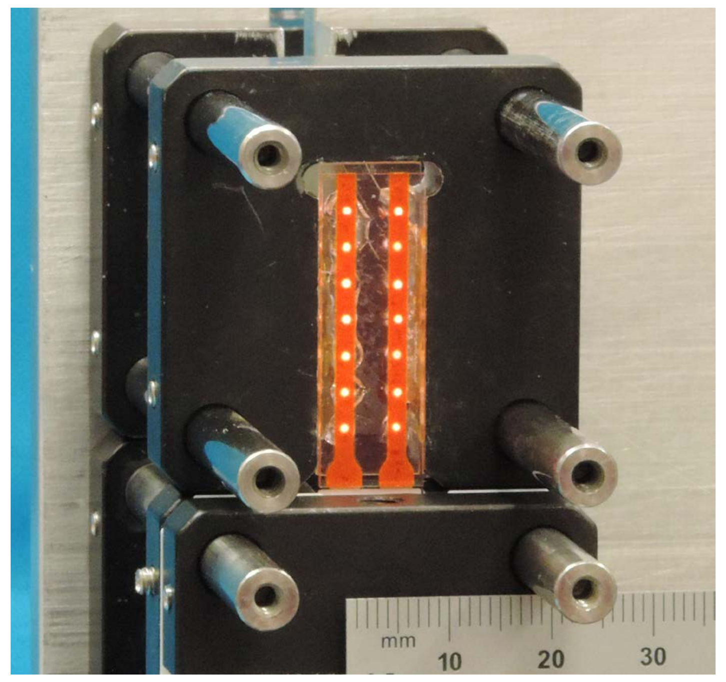
HNAB films crystallized at different temperatures.



Ion-polished cross-section of HNAB crystallized at room temperature.

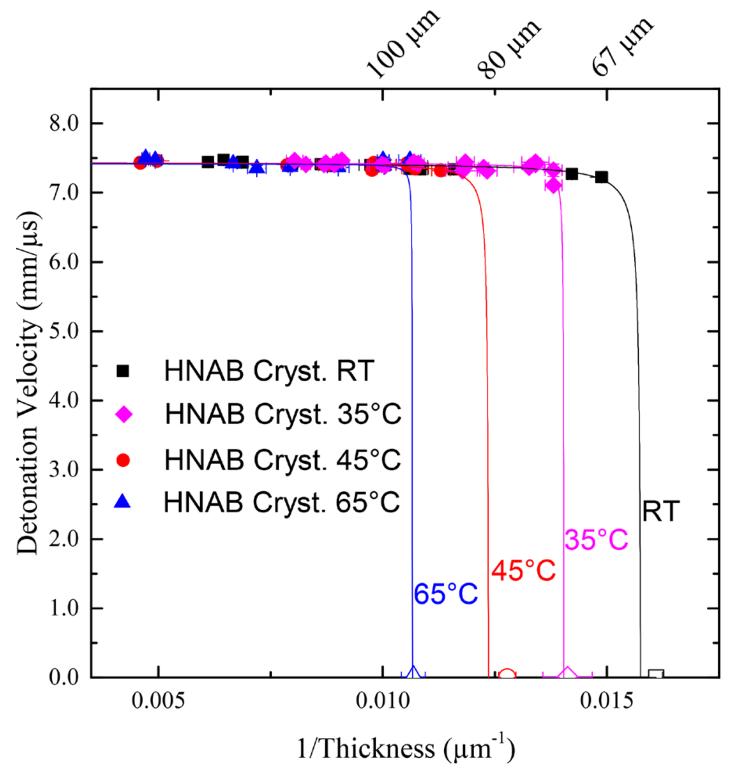
Detonation Experiments

- Sandia's critical detonation thickness experiment is used to measure detonation velocity in vapor-deposited explosives
- Optical fibers with precise spacing transmit detonation/shock light to a fast photodiode
- Confinement is provided by the substrate and sometimes deposited metals
- Vapor-deposited explosives with different preparation conditions can be studied with this experiment



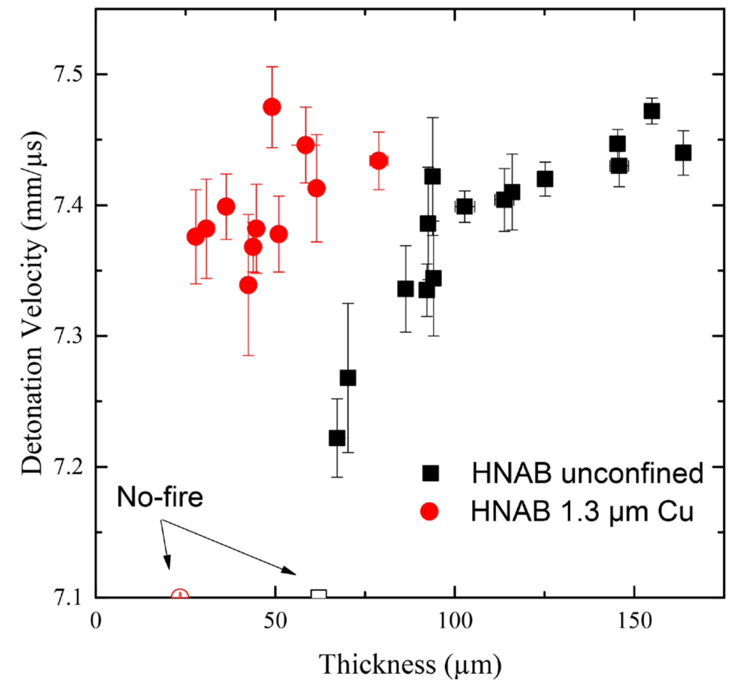
Photograph of Sandia's critical detonation thickness experiment with two deposited HNAB lines and backlighting to show the position of the optical fibers.

- Amorphous HNAB that is crystallized at higher temperatures (but below the glass transition temperature) has a different distribution of porosity than HNAB crystallized at room temperature
- The critical detonation thickness increases for HNAB crystallized at higher temperatures
- Amorphous HNAB (as deposited) and HNAB crystallized above the glass transition temperature (~70°C) have not been successfully detonated



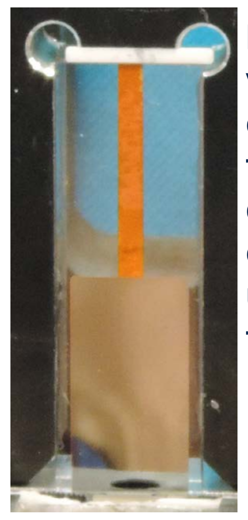
The detonation failure thickness of vapor-deposited HNAB increases with increasing crystallization temperature.

- HNAB has a low surface roughness, which allows continuous, thin confining layers to be deposited on the top and bottom of the deposited explosive
- Experiments using different confinement thickness can be used as an indirect probe of reaction zone length
- Confinement of just 1.3 µm of copper decreases the critical thickness from 63.4 ± 1.3 µm to 24.6 ± 1.1 µm

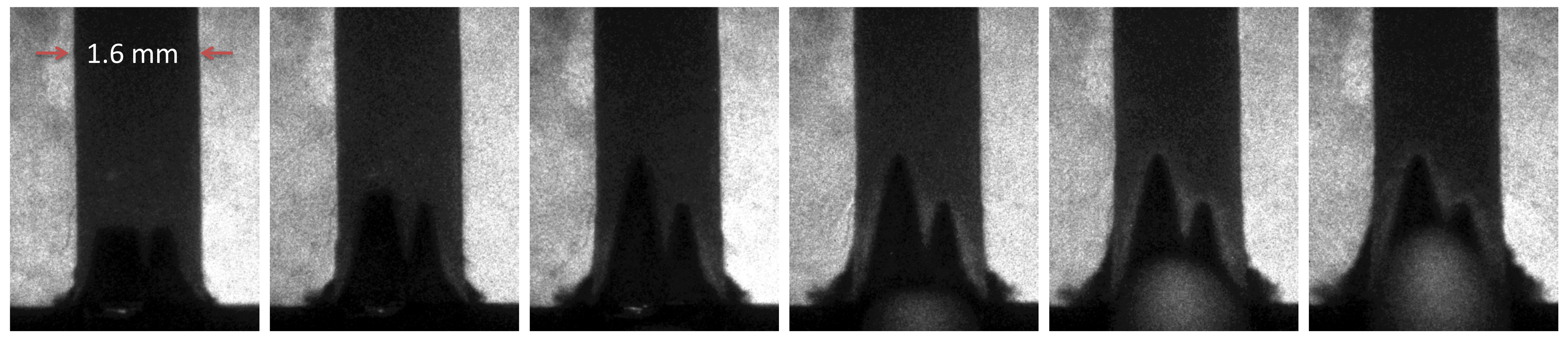


The detonation velocity of HNAB decreases with decreasing thickness, and confinement on HNAB films decreases the failure thickness.

- Vapor-deposited HNAB with a thickness of ~52 µm is between the unconfined and confined critical thickness
- Copper confinement (1.3 µm) on half of the film allows a failure location to be defined
- Detonation failure (below) is seen as a two tapered wedges that eventually extinguish



Photograph of a version of the critical detonation thickness experiment with copper confinement up the first half of the HNAB line.



Framing camera images of detonation failure in vapor-deposited HNAB (~52 µm) with loss of copper confinement (1.3 µm). Imaged with transmitted white light and reflected ~640 nm light. 10 ns exposure time, 14 MHz (1/70 ns) framing rate.

Conclusions

- Physical vapor deposition is a useful technique to prepare explosive films to study preparation-structure-property relationships
- Vapor-deposited HNAB is an interesting model explosive to study due to consistent microstructure, low surface roughness, and crystallization properties

Acknowledgements

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