SAND2017-5043C

Physical Vapor Deposition of Explosive Materials

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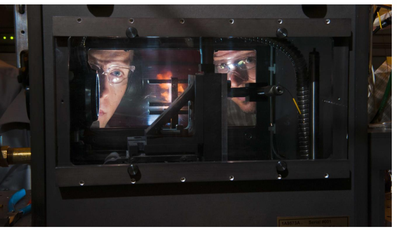

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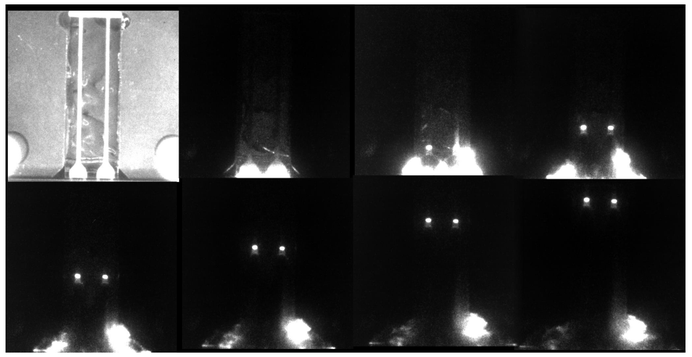
Background

This unique capability is centered around a custom built Physical Vapor Deposition (PVD) system designed specifically for the purpose of advanced microenergetic materials research.

- Multiple deposition source capabilities allow sequential deposition of a variety of materials without breaking vacuum
- Utilization of this technology has enabled new research in energetic materials science
- This process is being used to support modeling of energetic materials at small scales

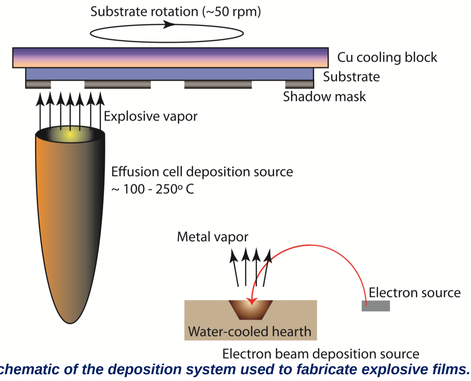
Purpose

Physical vapor deposition is an attractive method to produce sub-millimeter explosive samples for studying detonation behavior and microstructure effects at near failure conditions and geometries.



Framing camera images of detonation in deposited PETN lines. 1.67 million frames per second (1/600 ns), 20 ns exposure time.

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 and PETN
- Slower deposition rate (~ 5 μm/hr) for HNS
- The deposition of explosive materials can range from 1 – 500 microns in thickness
- Through the use of shadow masks, we are able to define geometry patterns with sub-millimeter resolution
- Metal confinement layers deposited using electron beam evaporation

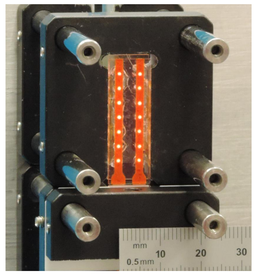
Challenges

- Substrate selection can be critical
  - Substrate material selection may cause film stress and delamination due to thermal expansion mismatch
  - Substrate selection can play a significant role in determining microstructure
- Source temperature controls deposition
  - Temperature is a limiting factor due to decomposition concerns
  - Vapor pressure is determined by temperature selection
  - Film growth rate and overall thickness can be limited by these factors
- Electron beam evaporation used for metal layers on explosives
  - Sputtering ⇒ too much kinetic energy, embeds below surface, can cause reactions/poor adhesion
  - Deposition rate important – too much thermal energy can decompose explosive
  - Delamination problems possible, may need adhesion layers to improve stability

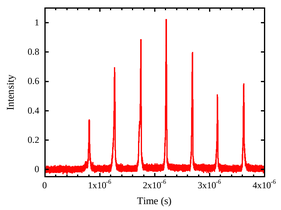
Metal films can be used to layer with explosive materials for the purpose of modifying surfaces or confining an explosive layer.

Detonation Confinement

- Confining an explosive with a dense, inert material is known to have substantial effects on failure geometry and detonation velocity near failure thickness
- Unique process for producing samples with intimate contact between metal and explosive layers
- We have performed experiments to determine effects of confinement in hexanitroazobenzene (HNAB) films confined with copper, and in hexanitrostilbene (HNS) or pentaerythritol tetranitrate (PETN) films confined with aluminum
- Detonation failure geometry decreases as confinement thickness increases until maximum confinement conditions are reached
- The minimum effectively infinite confinement condition can be used to indirectly measure detonation reaction kinetics

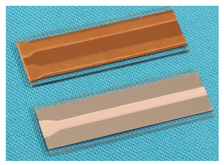


Detonation velocity/critical thickness experiment.

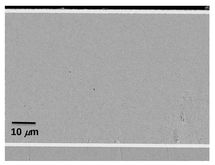


Example of oscilloscope data used to determine detonation velocity.

- 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



Photograph of Cu-confined HNAB and Al-confined HNS films.



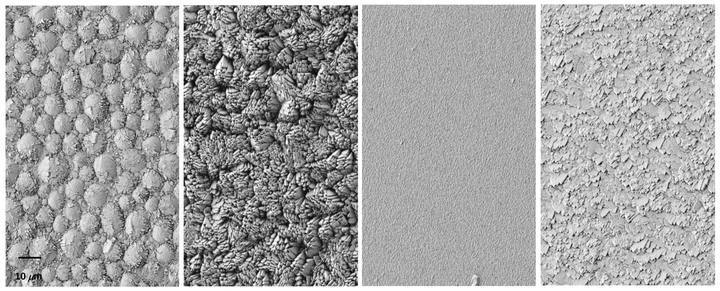
Ion-polished cross-section of a Copper/HNAB/Copper stack.

Microstructure

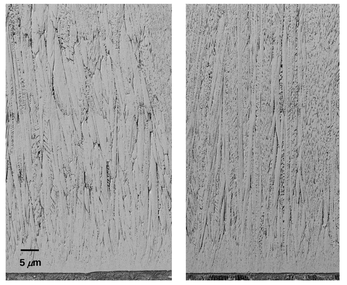
By varying deposition conditions, we can precisely control microstructure of the deposited films.

Surface/Interface Effects
- Adding layers between the substrate and explosive can substantially alter surface energies and subsequent film morphology
- Potential for significant changes in detonation behavior

Effects of deposition condition changes
- Microstructure changes can be induced by controlling substrate temperature



SEM image of the top surface of 6 mm and 35 mm thick PETN films on silicon with and without a 300 nm vapor-deposited aluminum layer on the substrate. The 10 μm scale bar applies to all images. (a) 6 μm, no Al, (b) 35 μm, no Al, (c) 6 μm, with Al, and (d) 35 μm, with Al



SEM images of ion-polished cross-sections of HNS films deposited at 10°C (a) and at 45°C (b). Image (a) illustrates a large columnar growth pattern with large non-uniform porosity, while image (b) illustrates narrower columns with smaller more distributed porosity.

Acknowledgements

This project was funded in part by Sandia's Laboratory Directed Research and Development Program and the Joint Department of Defense/Department of Energy Munitions Technology Development Program.

The authors would like to gratefully acknowledge the assistance of M. Barry Ritchey with SEM imaging, and J. Patrick Ball with detonation testing.

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