

Critical Detonation Thickness in Vapor-Deposited Pentaerythritol Tetranitrate (PETN) Films

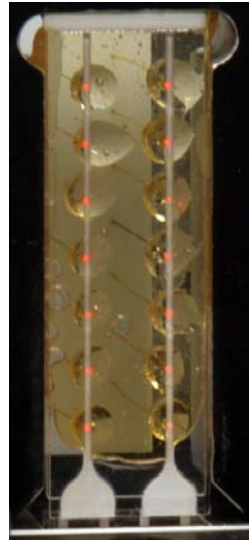
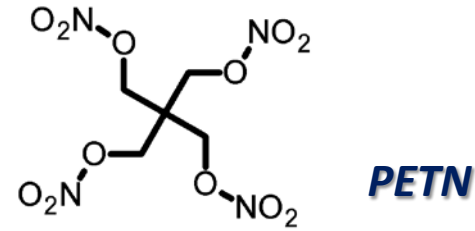
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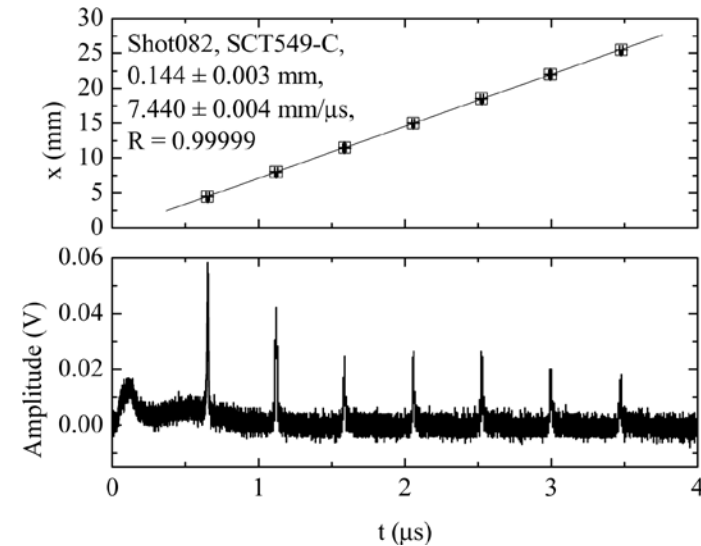
**The 17th American Physical Society
Topical Conference on Shock Compression of Condensed Matter,
Chicago, IL, 26 June – 1 July, 2011.**

Approach

- Thin PETN samples made by physical vapor deposition – different deposition conditions explored
- Detonation velocity measured for different deposition conditions by optical fiber probe technique
- Scanning electron microscopy used to analyze PETN cross-sections



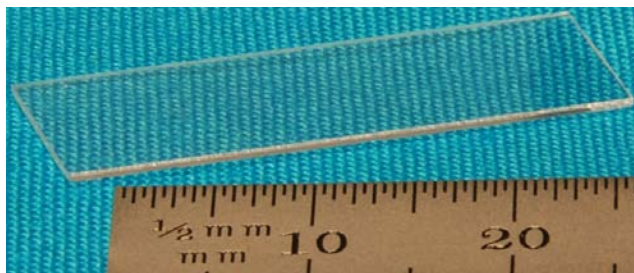
Photograph of optical fiber probe on PETN film.



Raw optical fiber probe data and analyzed x-t data – used to determine detonation velocity.

Physical Vapor Deposition is Used to Make Small-Scale PETN Samples

- Physical vapor deposition is used to sublime/evaporate PETN from a hot source onto a cool substrate
- Substrates are $0.5 \times 10.0 \times 30.0$ mm fused silica
- Shadow masks are used to pattern lines of PETN
 - 1.00 mm width used in this study
- Deposition time and amount of PETN in source controls thicknesses ($0.112\text{--}0.202\text{ }\mu\text{m}$)



Photograph of bare substrate next to substrate with deposited PETN films.



Previous Work

- **Microstructure in vapor-deposited PETN is dependent on deposition conditions**
 - Substrate material, substrate temperature, deposition rate
- **Critical thickness for detonation is dependent on deposited film geometry**
 - Deposited film width affects side losses during detonation propagation

Knepper, R., Tappan, A.S., Wixom, R.R., and Rodriguez, M.A., "Controlling the microstructure of vapor-deposited pentaerythritol tetranitrate films," *Journal of Materials Research*, in press, 2011
Tappan, A.S., Knepper, R., Wixom, R.R., Marquez, M.P., Miller, J.C., and Ball, J.P., "Critical Thickness Measurements in Vapor-Deposited Pentaerythritol Tetranitrate (PETN) Films," *14th International Detonation Symposium*, Coeur d'Alene, ID, April 11-16, 2010.

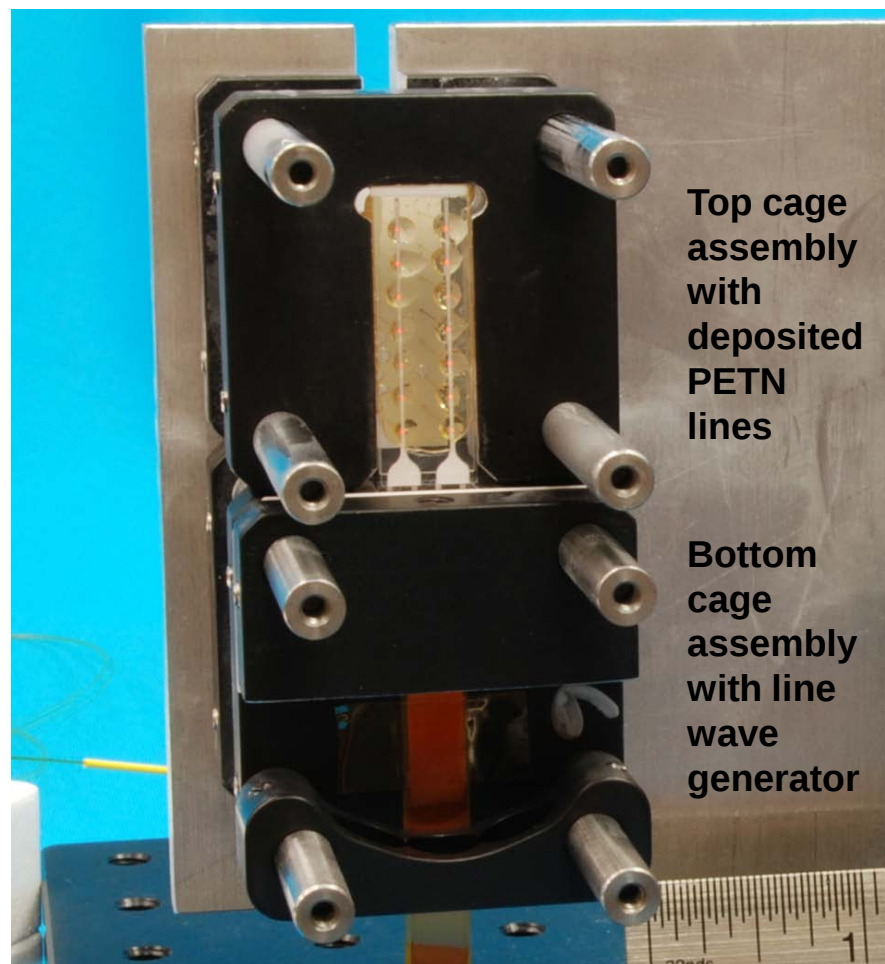
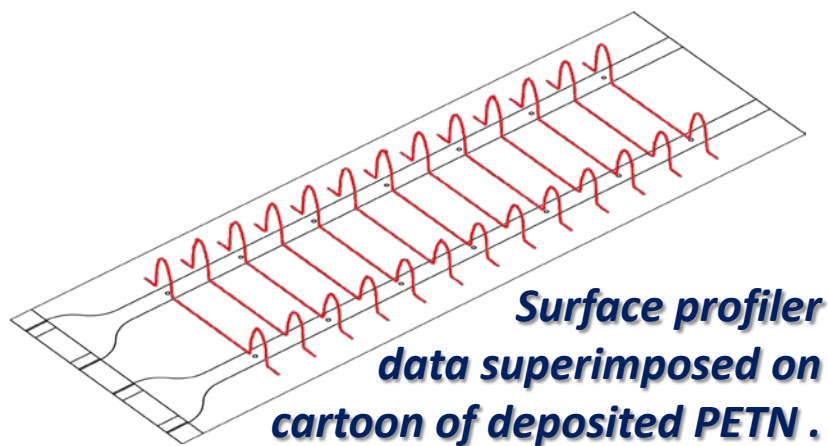
Deposition Conditions

- **Four deposition conditions explored through differences in substrate cooling**
- **Previous work (International Detonation Symposium, 2010) involved lower cooling capacity and 0.80 mm wide lines**

Substrate Cooling Capacity	Substrate Contact	Substrate Holder Temperature
		deg. C
Poor	N/A	N/A
Good	Poor	10
Good	Good	10
Good	Good	22

Detonation Velocity Measured as a Function of Deposition Thickness

- Film thickness measured using stylus surface profiler
- Critical thickness for detonation determined



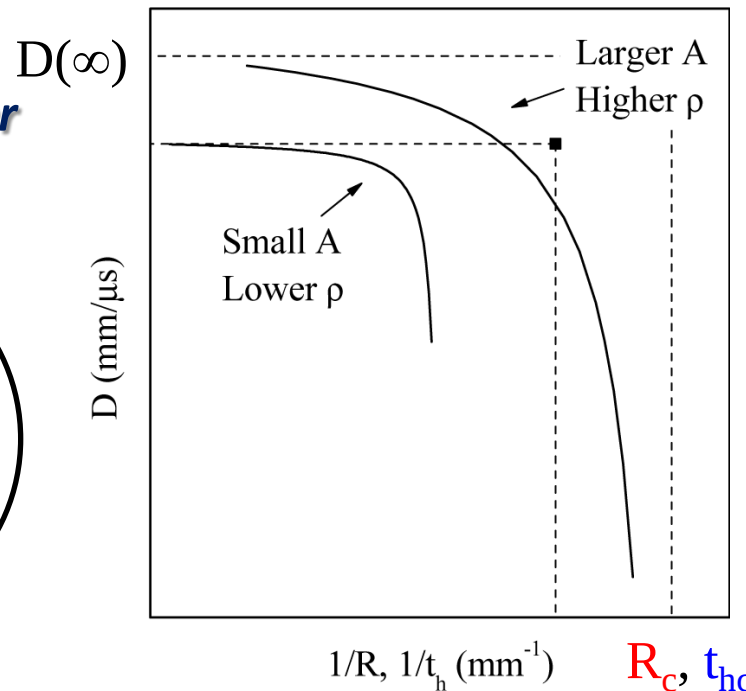
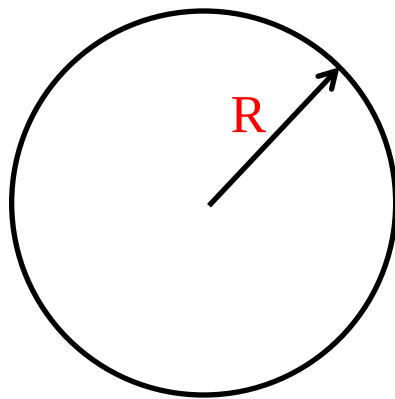
Critical thickness experiment.

Data Analysis Is Conducted Using the Standard Critical Diameter Form

$$D(R) = D(\infty) \left[1 - \frac{1}{R} \left(\frac{A}{1 - R_c \frac{1}{R}} \right) \right]$$

$$D(R) = D(\infty) \left[1 - \frac{1}{t_h} \left(\frac{A}{1 - t_{hc} \frac{1}{t_h}} \right) \right]$$

Critical diameter configuration.



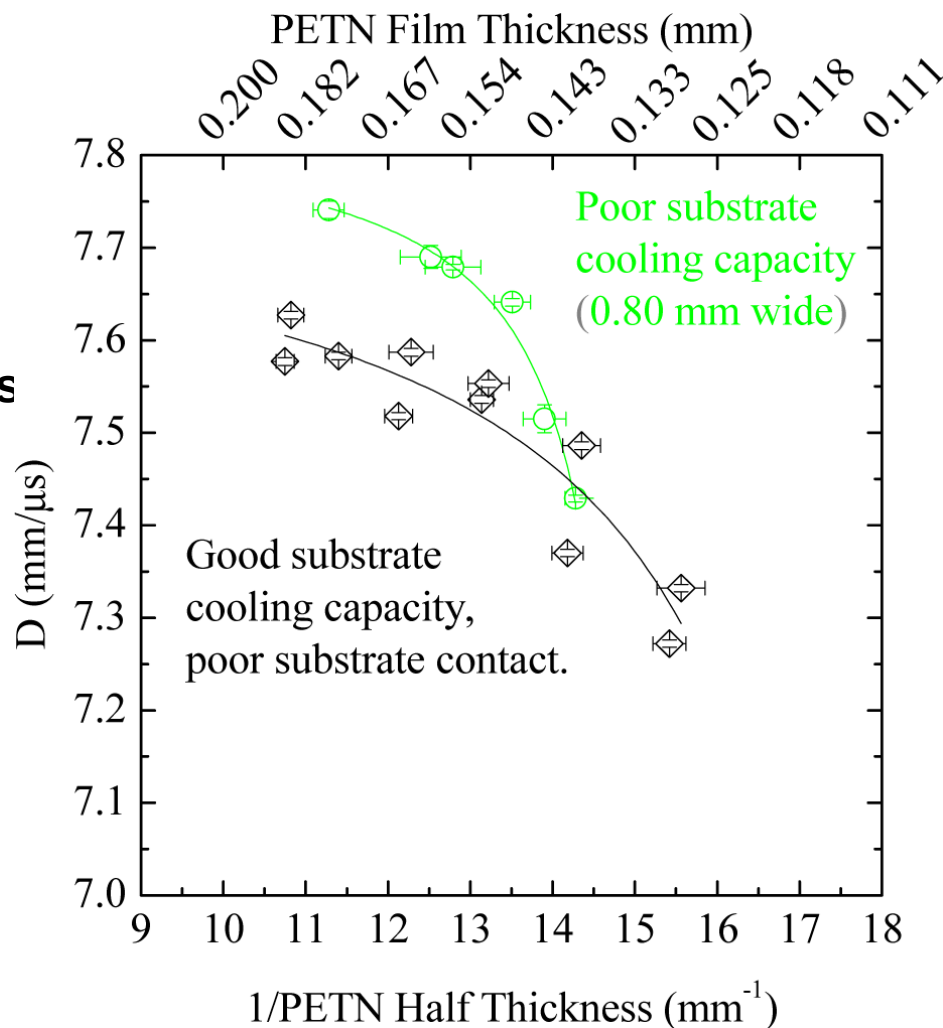
Critical thickness configuration.



Critical Thickness Comparison – Substrate Cooling Capacity

- **Higher substrate cooling capacity:**
 - **Smaller critical thickness**
 - **Lower infinite velocity – less dense**
 - **Larger length param. – less homogeneous**

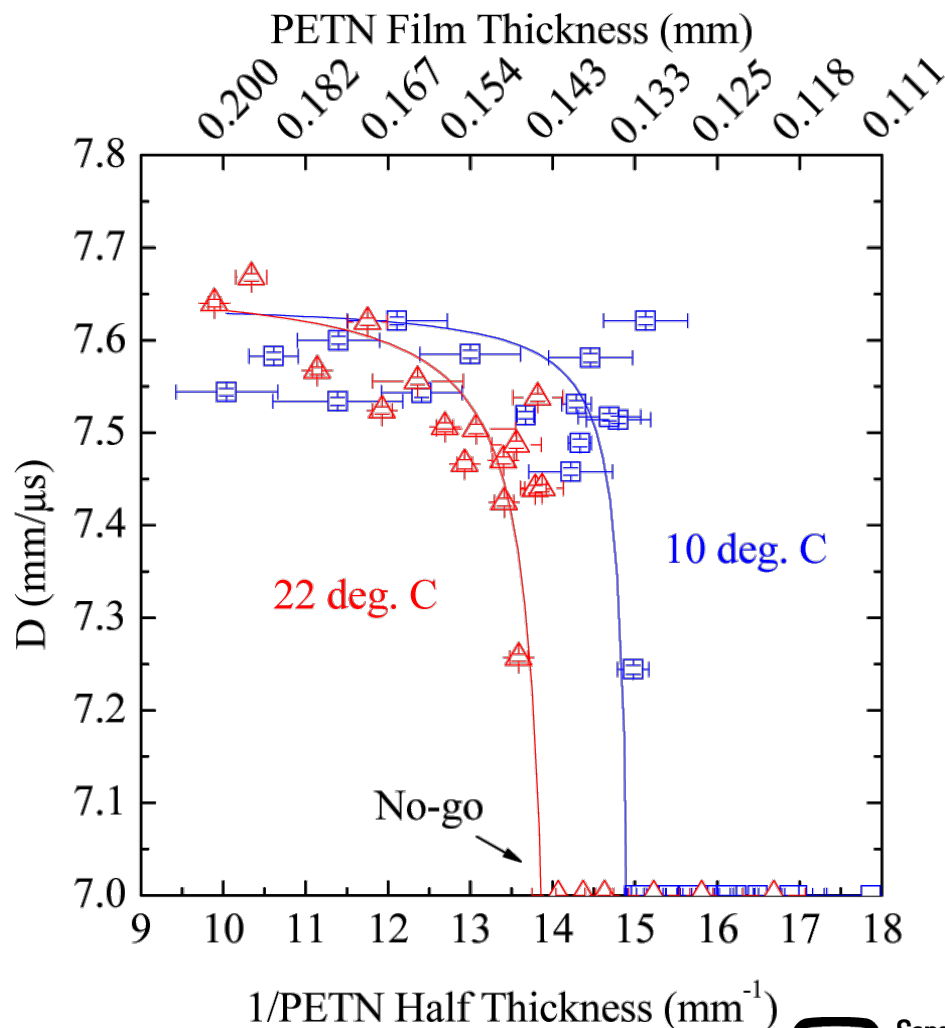
Detonation Velocity at Infinite Thickness, $D(\infty)$	Critical Thickness, t_c	Length Parameter, A
mm/ μ s	mm	mm
7.82 $\pm$ 0.05	0.131 $\pm$ 0.003	0.0002 $\pm$ 0.0001
7.72 $\pm$ 0.10	0.107 $\pm$ 0.014	0.0006 $\pm$ 0.0005



Critical Thickness Comparison – Substrate Temperature

- **Lower substrate temperature:**
 - **Smaller critical thickness**
 - **Similar infinite velocity**
 - **Smaller length param. – more homogeneous**

Detonation Velocity at Infinite Thickness, $D(\infty)$	Critical Thickness, t_c	Length Parameter, A
mm/ μ s	mm	mm
7.64 $\pm$ 0.28	0.133 $\pm$ 0.000	0.00004 $\pm$ 0.00004
7.66 $\pm$ 0.28	0.142 $\pm$ 0.000	0.0001 $\pm$ 0.00004

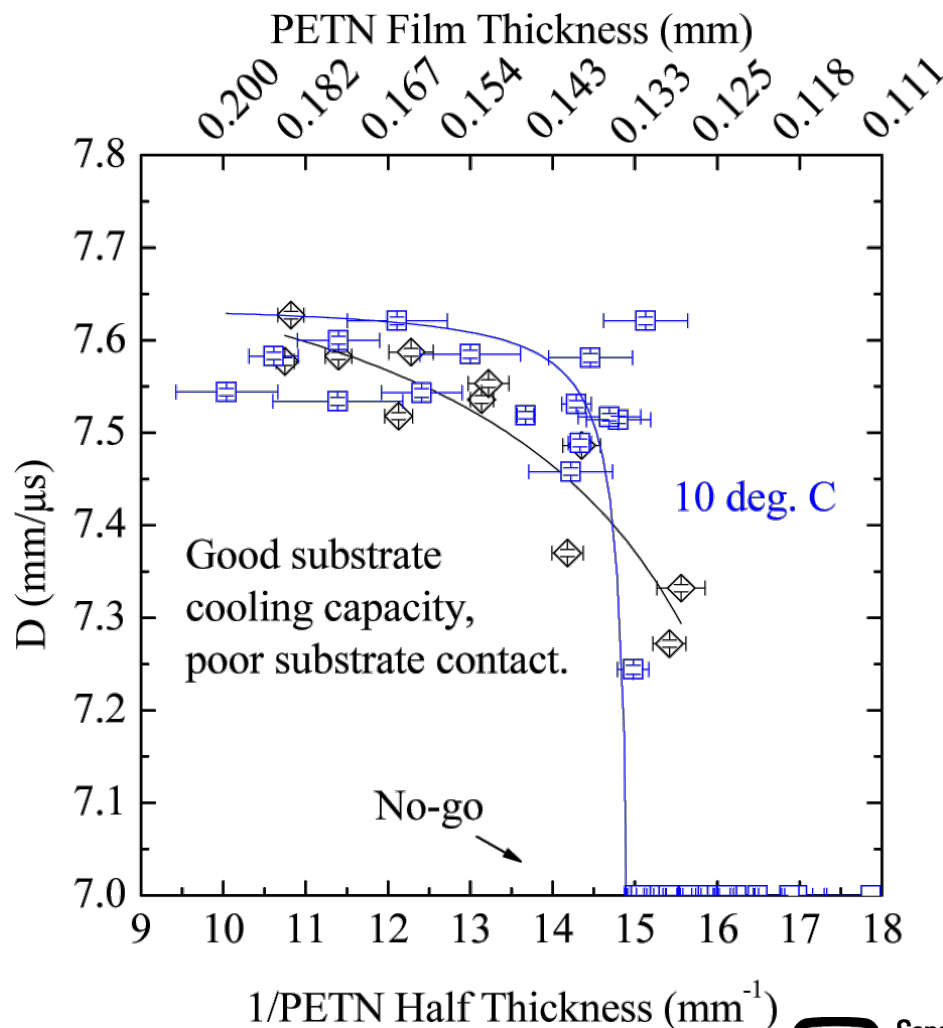


Critical Thickness Comparison – Substrate Contact

- **Better substrate contact with cooling block:**

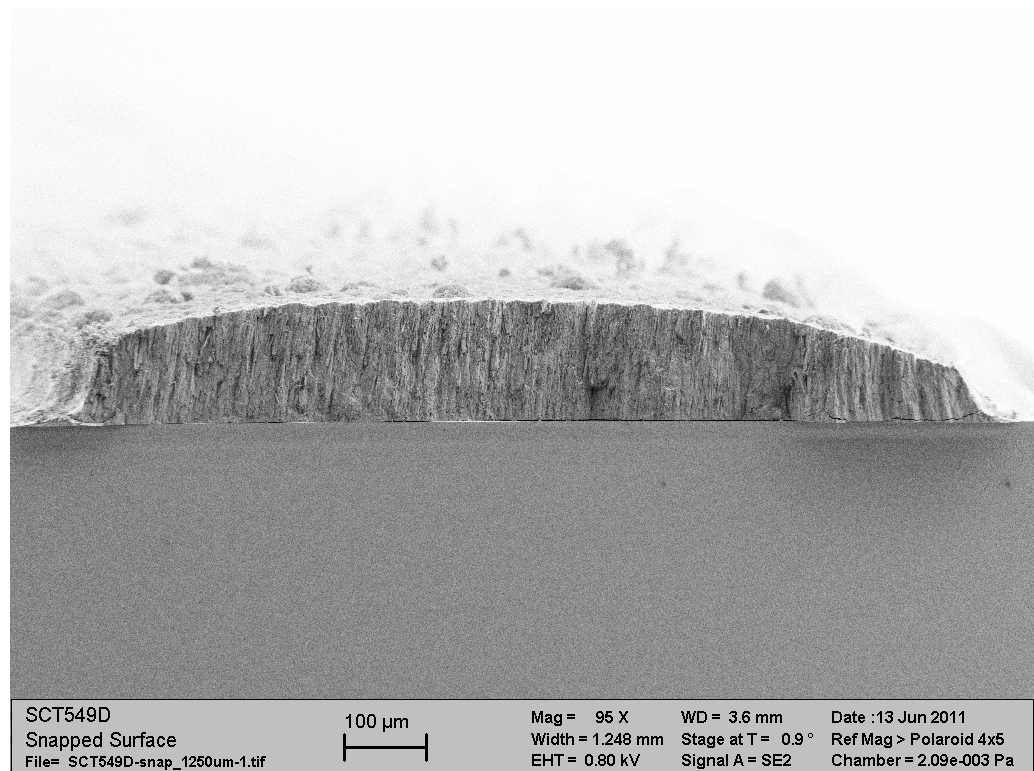
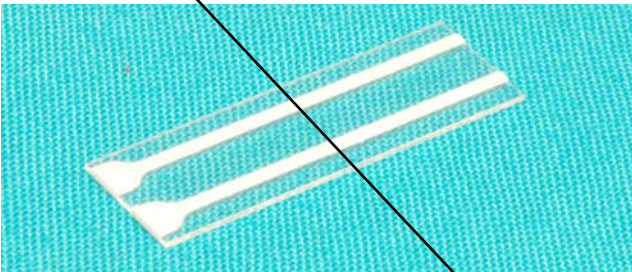
- **Larger critical thickness**
- **Similar infinite velocity**
- **Smaller length param. – more homogeneous**

Detonation Velocity at Infinite Thickness, $D(\infty)$	Critical Thickness, t_c	Length Parameter, A
mm/ μ s	mm	mm
7.64 ± 0.28	0.133 ± 0.000	0.00004 ± 0.00004
7.72 ± 0.10	0.107 ± 0.014	0.0006 ± 0.0005



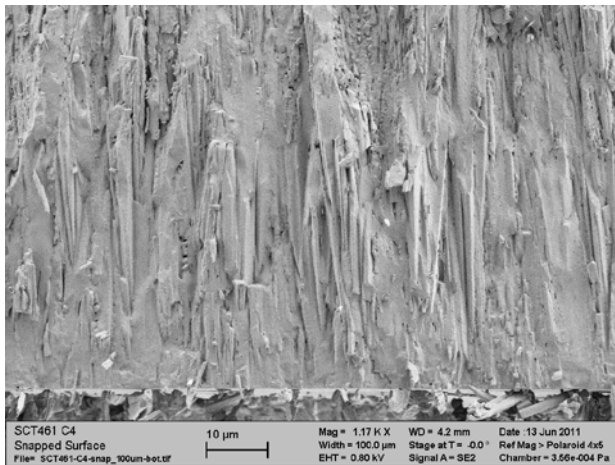
PETN Films Are Snapped for SEM Analysis of Cross-Section

- Fused silica substrates are broken across scribe line

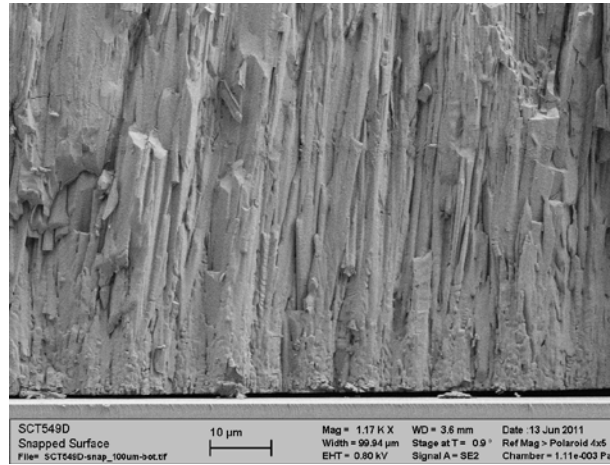


Scanning electron micrograph of cross-sectioned PETN film on fused silica substrate.

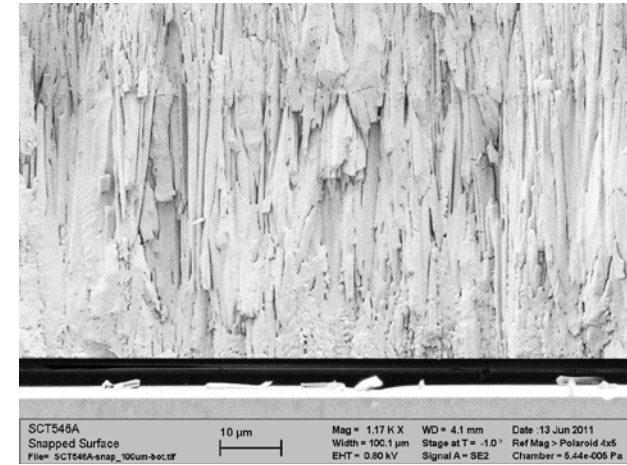
Microstructure does not show obvious differences with deposition conditions



SEM of PETN, Poor substrate cooling capacity.



SEM of PETN, Good substrate cooling capacity, 22 °C.



SEM of PETN, Good substrate cooling capacity, 10 °C.



Conclusions

- **Deposition conditions affect critical thickness behavior of vapor deposited PETN**
- **Higher cooling capacity of substrate holder:**
 - **Smaller critical thickness and smaller infinite velocity**
- **Lower substrate temperature:**
 - **Smaller critical thickness**
 - **Similar infinite velocity**
- **Better substrate contact with cooling block:**
 - **Larger critical thickness**
 - **Similar infinite velocity**
 - **Smaller length parameter – more homogeneous**
- **Funding: Joint Department of Defense/Department of Energy Munitions Technology Development Program**
- **Thanks to: M. Barry Ritchey, Marc Basiliere, Rosa Montoya, Adrian Casias, David Saiz, Thomas Gutierrez, Tim Turner**