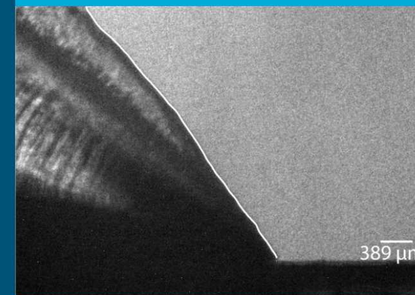
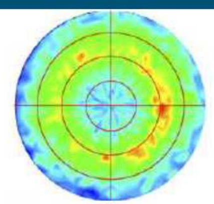
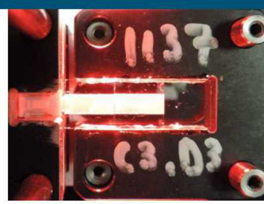
SAND2018-7146C

Effect of Microscale Defects on Shock and Detonation Propagation in Pentaerythritol Tetranitrate (PETN) Films







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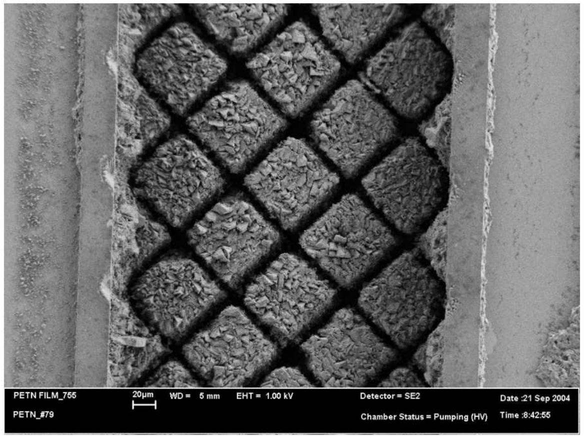
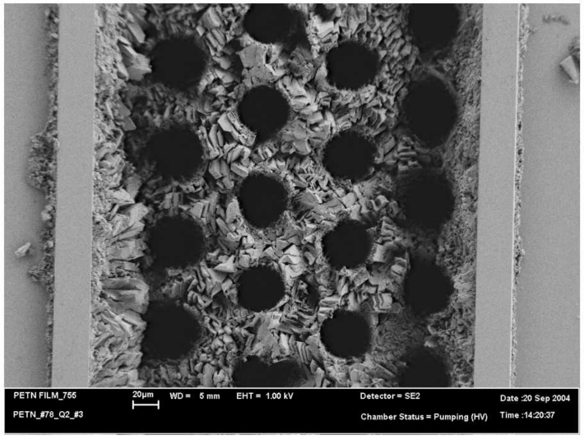
Presentation Outline

- **Motivation**
- Experimental
- Results and Discussion
- Conclusion and Future Work

Microenergetics

- Microscale processing and testing of energetic materials has enabled investigation into the field of "*microenergetics*."
- MEMS-based fabrication techniques on energetic films has enabled study of detonation phenomena (initiation threshold, critical detonation thickness, detonation velocity, etc.) at micron-length scales.



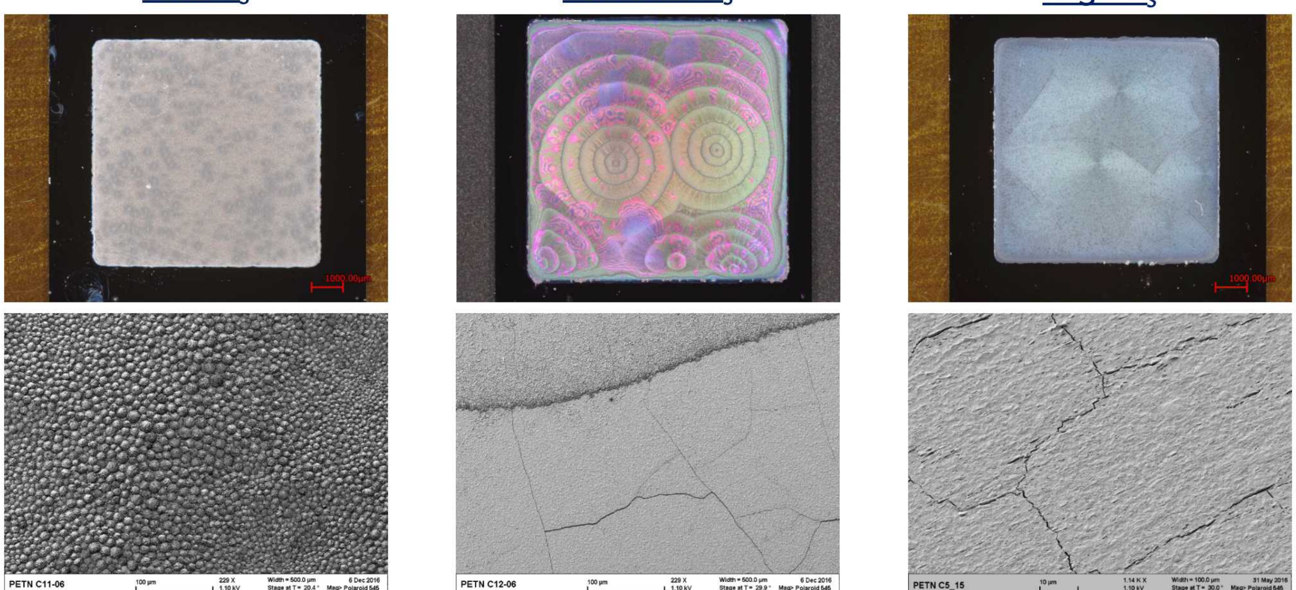


PETN films patterned using femtosecond laser micromachining (left) and plasma etching (right). Scale bar is 50 µm. (**Tappan et al.**, ***Int. Det. Symp.***, **2006**)

Film Growth of High Explosives

- Physical vapor deposition (PVD) of organic high explosives has enabled unprecedented level of control over explosive material morphology.
- We've demonstrated that interfacial energy, between substrate and energetic, strongly influences crystal orientation of explosive, and in turn, density, porosity, and other parameters relevant to detonation.
  - Increased surface energy leads to cracking and other defects in film.
  - **We investigate effect of microscale defects on detonation propagation and failure.**

Low E_s | Medium E_s | High E_s



Optical microscopy (top) and SEM images (bottom) of PETN films grown via PVD. Changes in morphology are due to interfacial energy.

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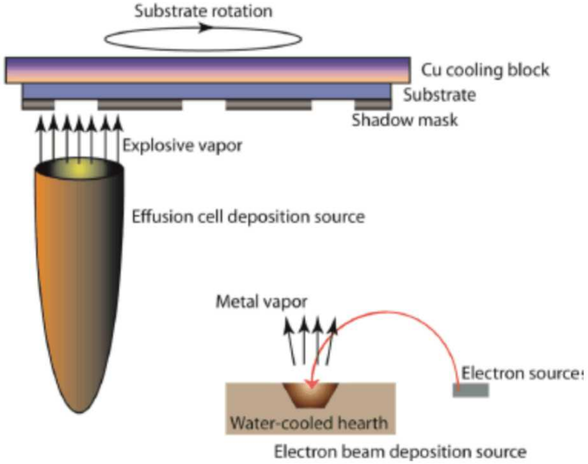
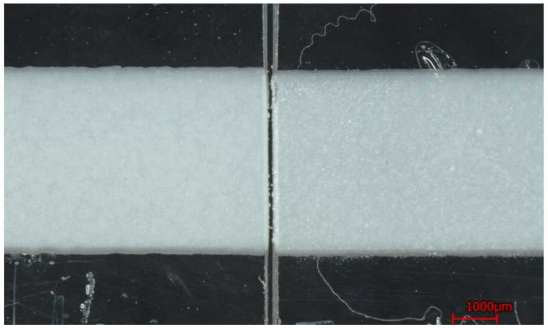
Microdetonation Sample Preparation

- Polycarbonate substrates used to match thermal expansion of PETN and limit uncontrolled cracking.
- PETN films deposited via physical vapor deposition (PVD) under high vacuum.
  - Target film thickness of 200 μm, measured value across all films was 211 μm ± 8 μm.
- Engineered gaps constructed to simulate defects in explosive films.
  - Gap size ranged from 25 μm to over 100 μm.

Custom high vacuum chamber for PVD of energetics (top) and schematic of deposition process (bottom).

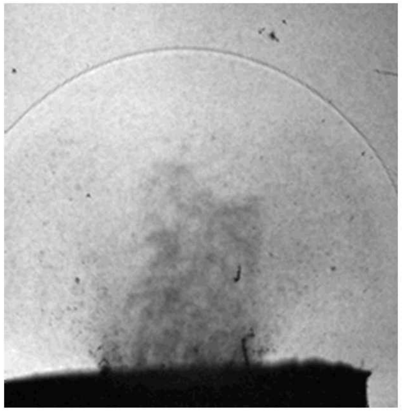


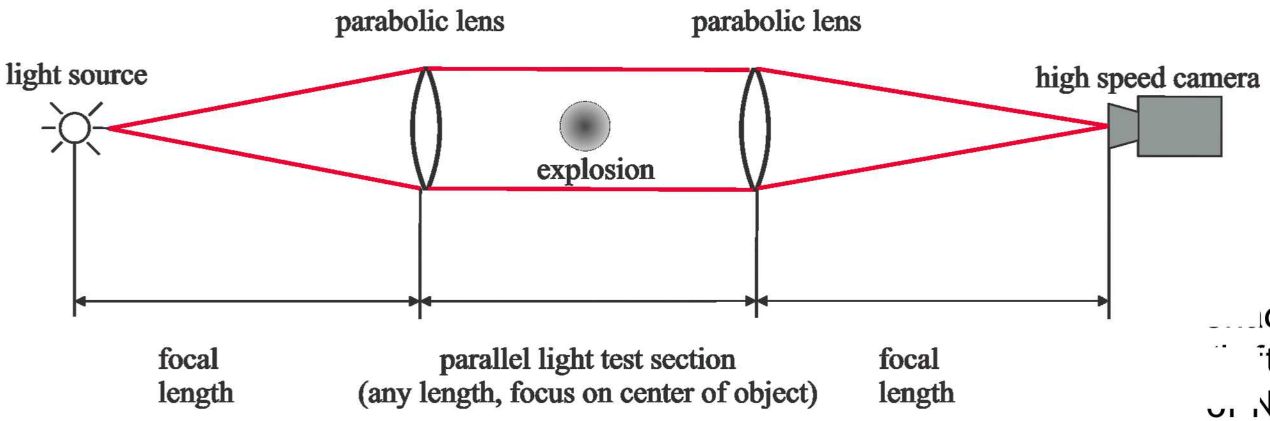


Optical microscopy of engineered gap, ~95 μm across.

Ultra-high Speed Shadowgraph Imaging

- Focused shadowgraph visualizes second spatial derivative of the refractive index.
  - Shock wave appears as thin dark line due to sharp discontinuity.
  - Allows for determination of air shock velocity and estimation of detonation wave velocity at shock/detonation wave interface.
- SIMX-15 ultra-high speed framing camera (Specialised Imaging) used to capture detonation phenomena.
  - Frame rates up to 67 MHz (1/15 ns), 10 ns exposure.



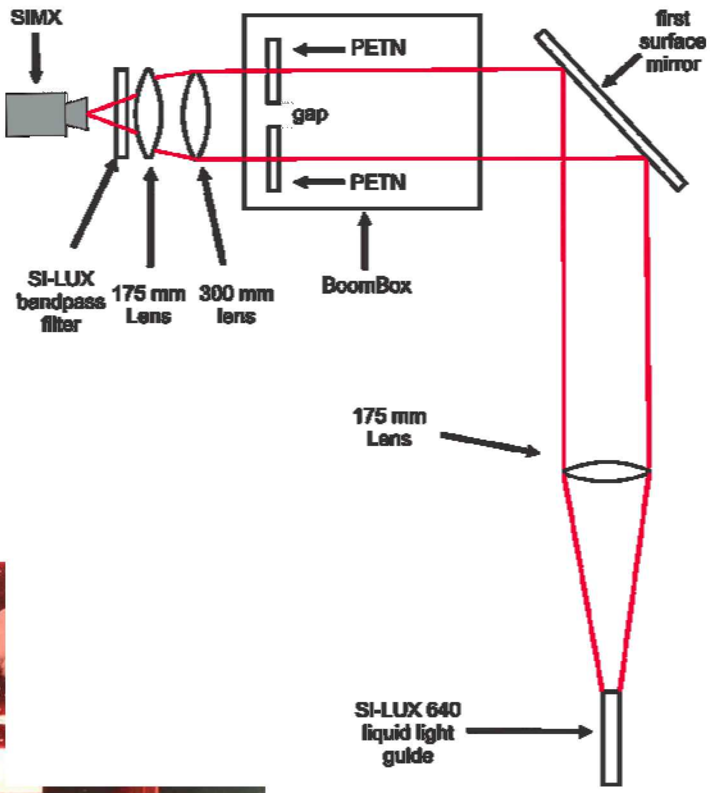


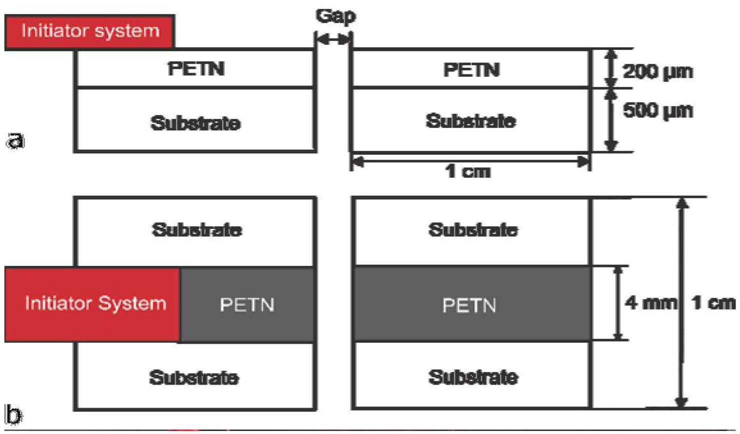
…dowgraph imaging principle
…t) and example shadowgraph
… NONEL lead line (above).

Microdetonation Experiment Layout

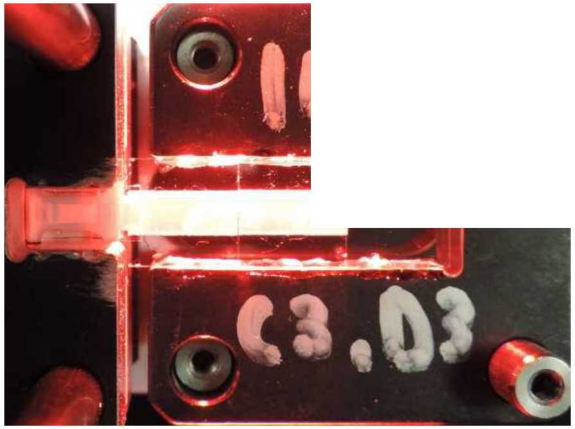
- PETN samples built up in fixtures.
  - Continuous film (1 cm × 3 cm substrate).
  - ‘Infinite’ gap (image at end of sample).
  - Controlled gap size (25 µm to >100 µm).
- Ultra-high speed shadowgraph imaging optics set up in configuration shown.

Layout of Microdetonation Imaging Setup.





Schematic showing (a) side-on and (b) top-down view of sample layout.



Photograph showing top-down view of PETN gap sample in fixture.

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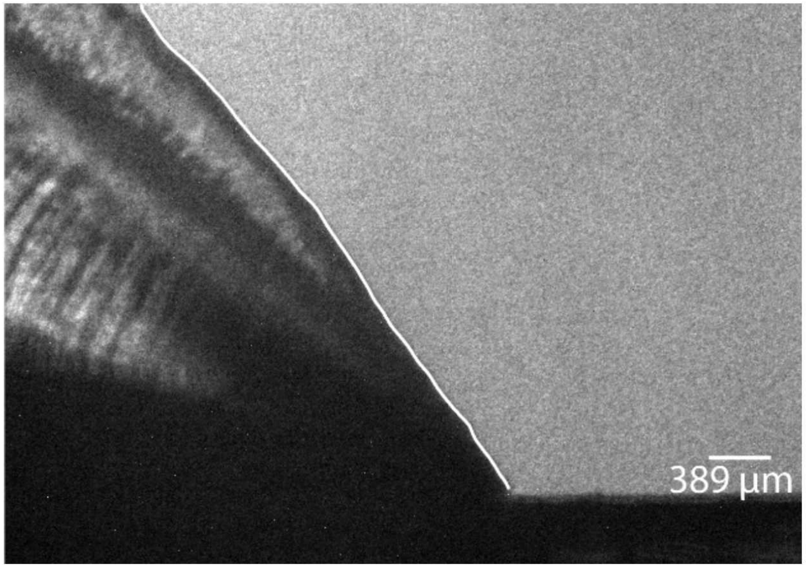
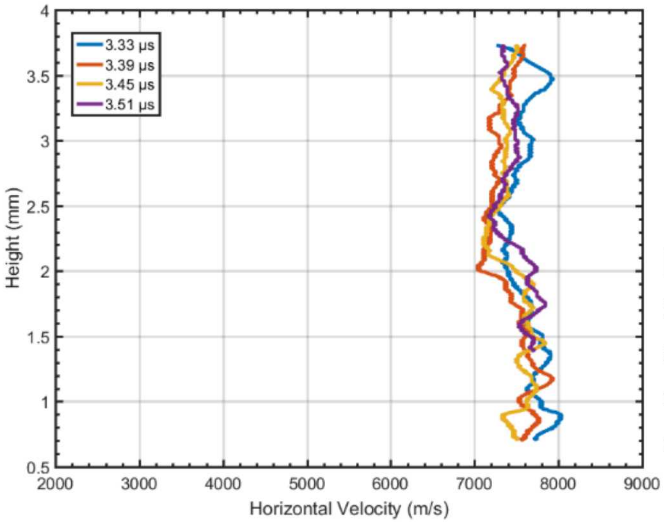
Continuous PETN Film

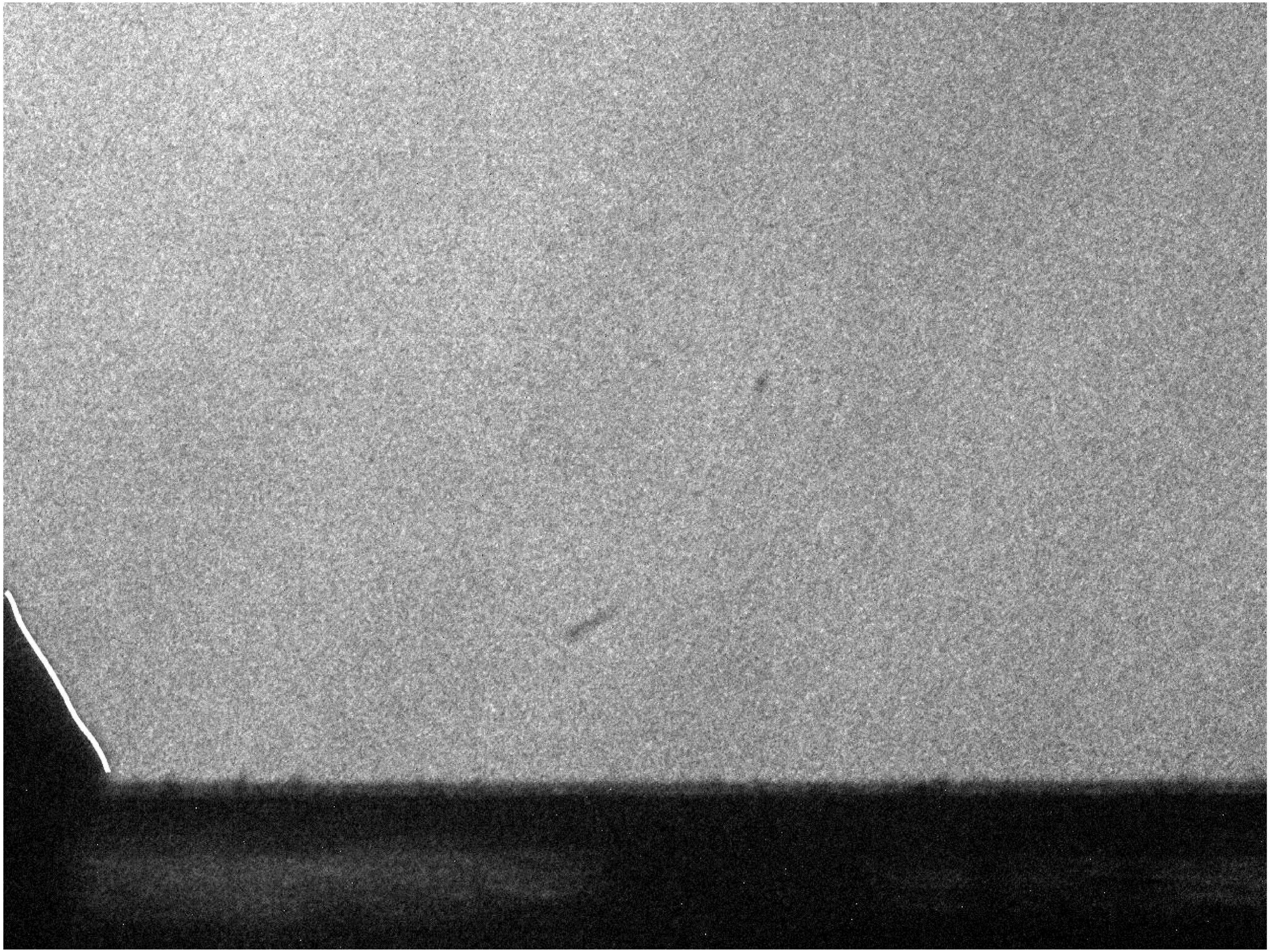
- Continuous film (4 mm wide PETN on 1 cm × 3 cm substrate) served as control case with uninterrupted detonation propagation.
- White line on shadowgraph denotes shock front identified and tracked by MATLAB image processing algorithm.
- Air shock velocity remains relatively steady across field of view and with time, although small discontinuities exist.
  - v_0=7.0 to 8.0 km/s.
  - Note for PETN, D_∞=8.27 km/s.



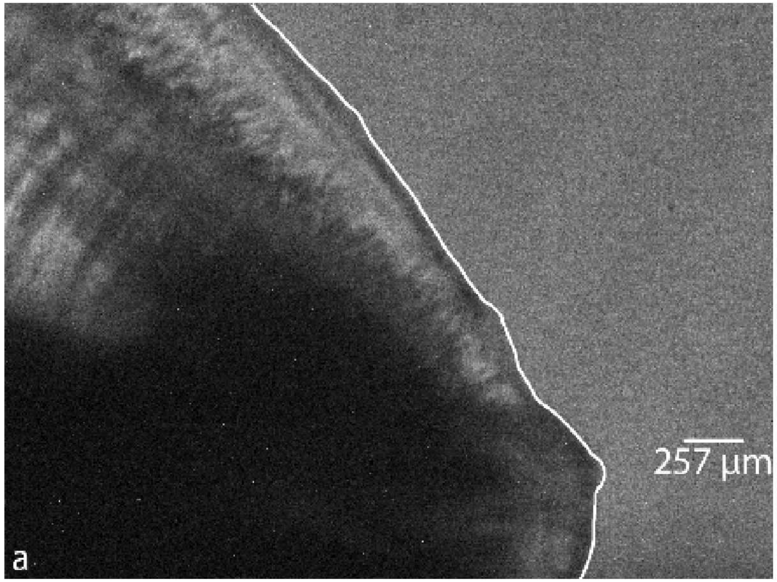


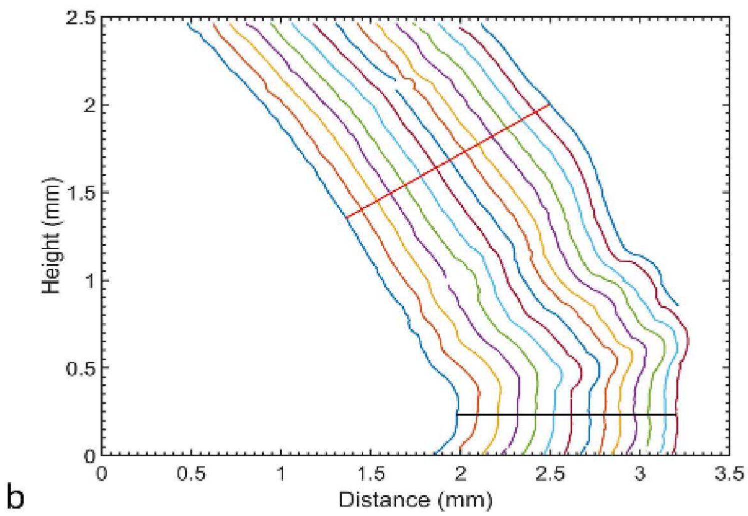
Horizontal shock velocity as a function of time after detonation.

Continuous PETN Film

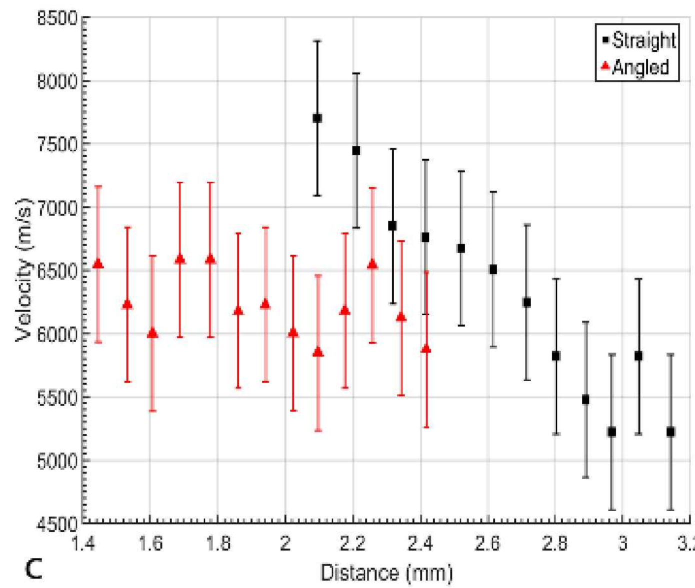


'Infinite' Gap



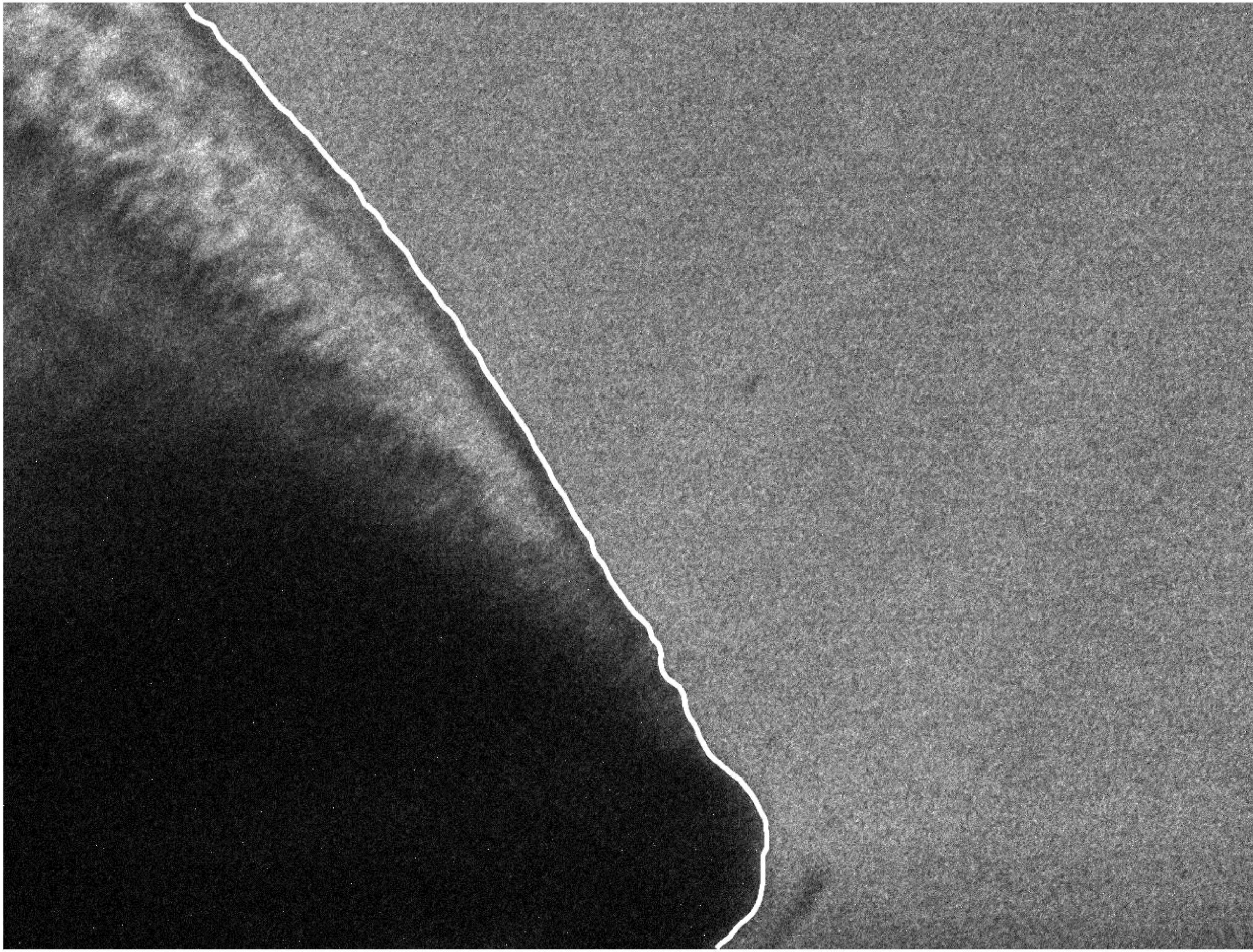


- 'Infinite' gap test case provides bound for shock velocity and profile decay into free space (air).
- Curvature of shock wave increases after passing edge of sample.



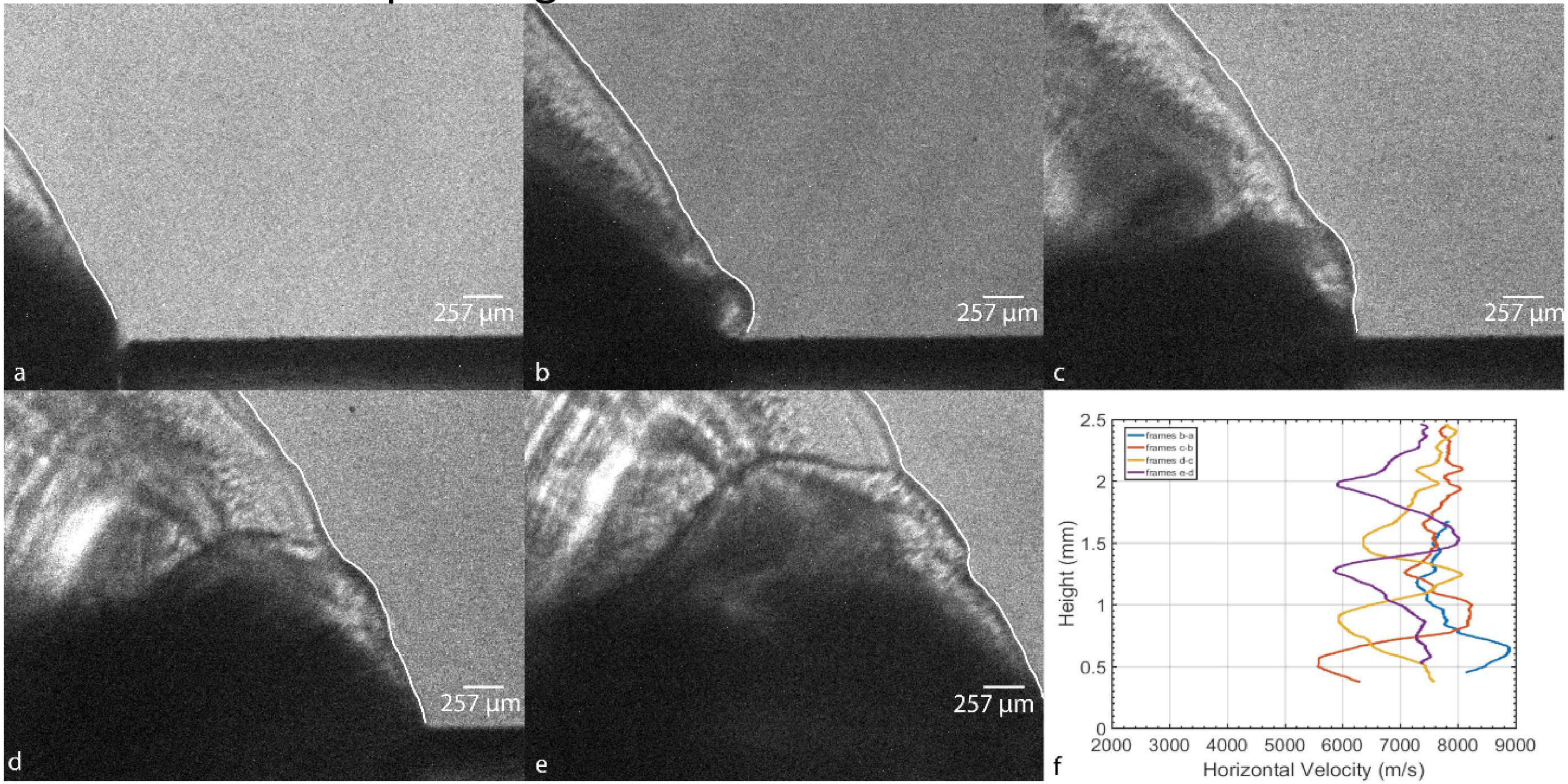
(a) Shadowgraph of shock wave, (b) shock wave profile with distance from initiation, (c) horizontal and perpendicular shock velocity components.

'Infinite' Gap



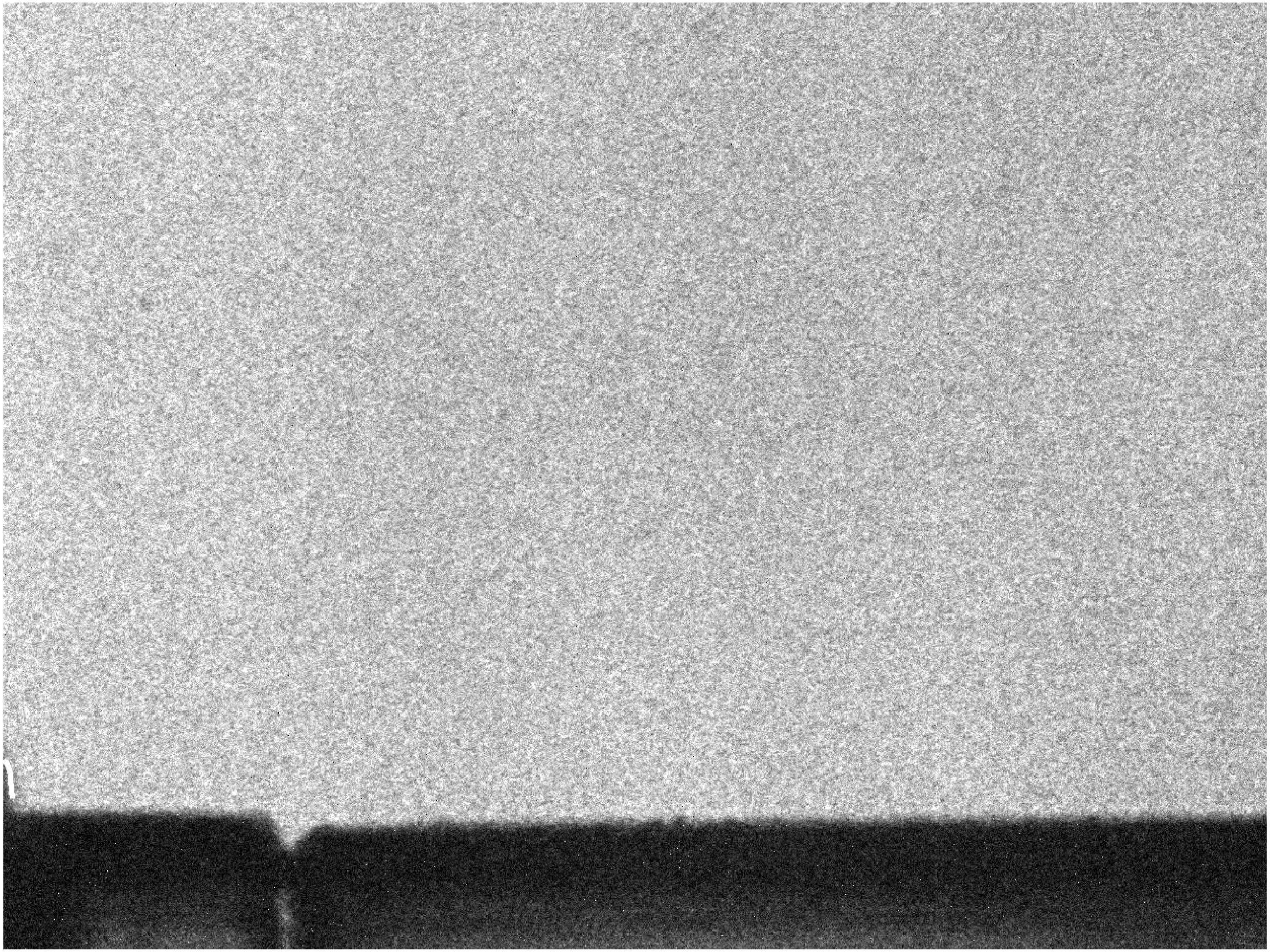
25 μm Gap (Detonation Propagation)

- Propagation of shock wave across gap results in reignition of PETN.
- Shock velocity initially decelerates when crossing gap, then reaccelerates upon reignition of PETN.



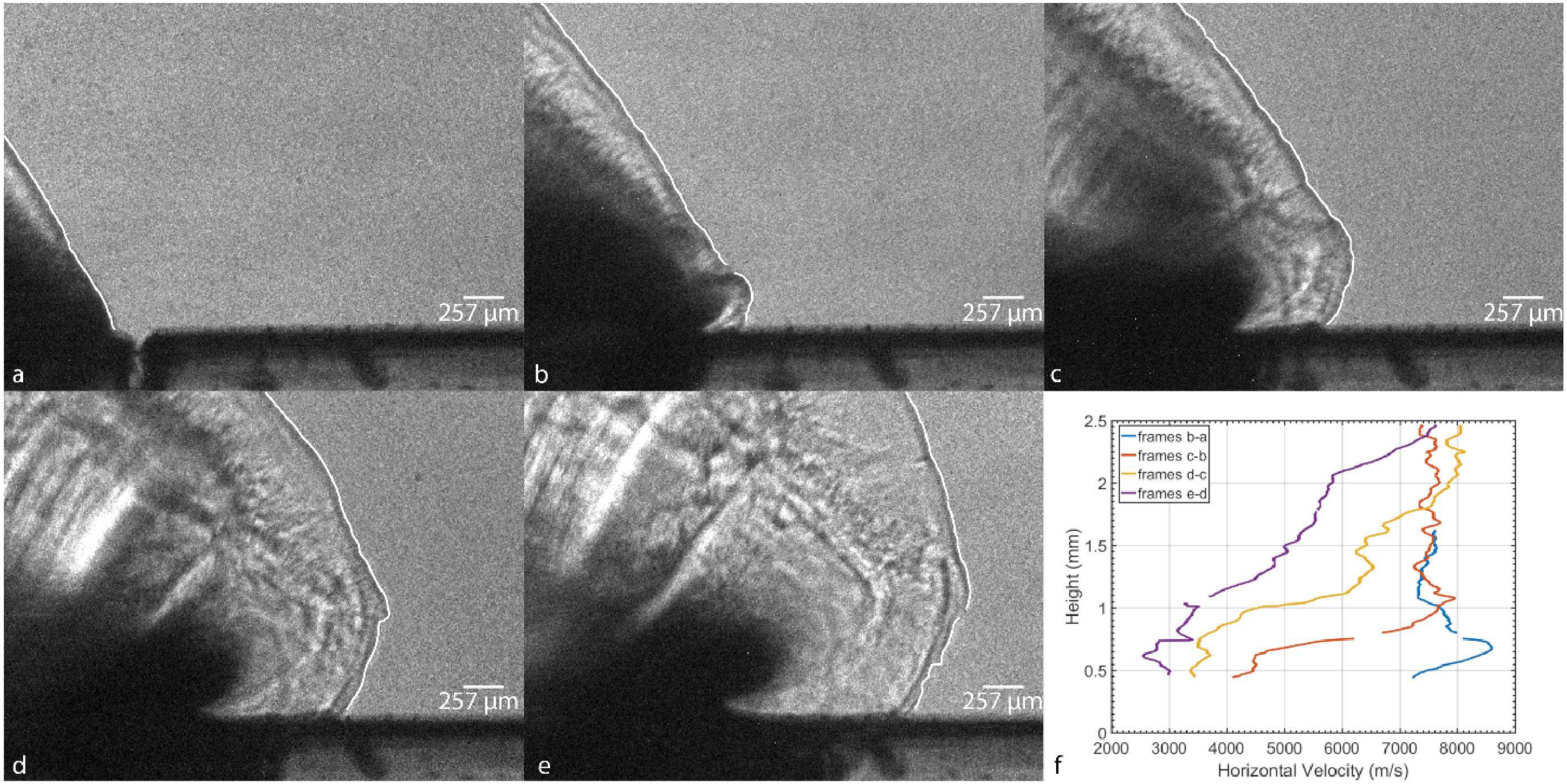
Shock wave (a) before and (b-e) after crossing 25 μm gap. (f) Backward difference velocity along height of shock wave.

25 μm Gap (Detonation Propagation)



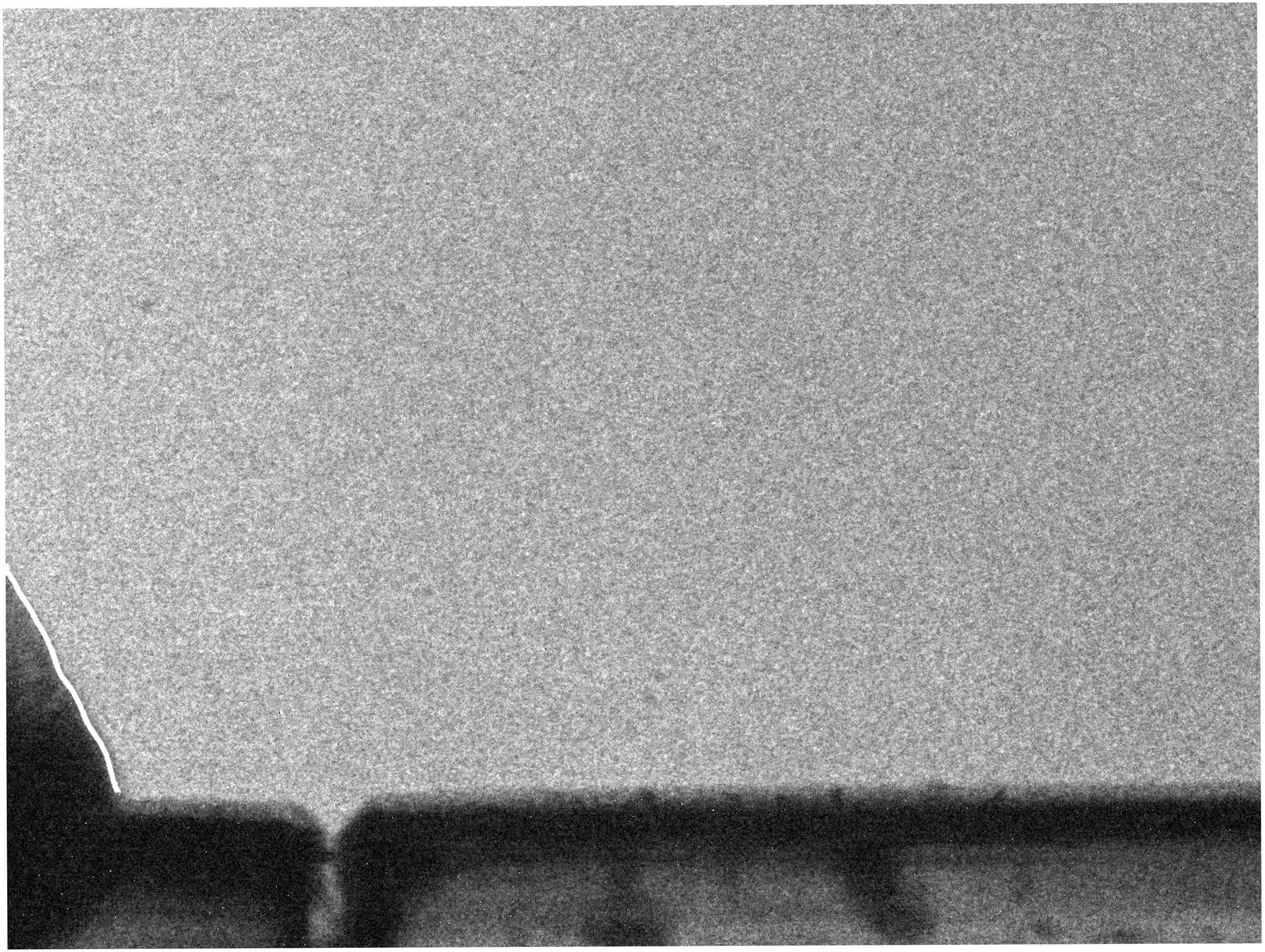
93 µm Gap (Detonation Failure)

- Detonation failure occurs after crossing gap.
- Continual deceleration of shock wave observed.



Shock wave (a) before and (b-e) after crossing 93 µm gap. (f) Backward difference velocity along height of shock wave.

93 μm Gap (Detonation Failure)



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Conclusion

- Results indicate a critical gap size for reliable reignition of PETN films to be approximately 75 µm or less.
  - In one instance, reignition occurred across a gap larger than 80 µm, but this was likely due to non-uniform gap distance with bridging in at least one location.
- Decay in air shock velocity and increased curvature due to presence of gap in the PETN films mimics effect of air shock traveling into free space ('infinite' gap).
- Significant instabilities in air shock above explosive result from microscale defects, but steady-state condition re-establishes after reignition.
- Microcracking observed in densified samples likely won't cause detonation failure, but may affect detonation wave velocity and stability.

Future Work

- Developing improvements to ultra-high speed shadowgraph imaging setup.
- Investigating effects of confinement on detonation failure threshold across microscale defects.
- Interest in determining influence of PETN film thickness on detonation failure threshold with presence of defects.
- Pursuing density modification of PETN films through interfacial energy enhancement.
- Modeling and validation in CTH Shock Physics software.

Questions?

Acknowledgements

Barry Ritchey (Sandia) is gratefully acknowledged for acquiring SEM images of PETN samples.

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