SAND2017-7052C

Exceptional service in the national interest

Sandia National Laboratories

Detonation corner turning in vapor-deposited explosives using the micromushroom test

Alexander S. Tappan, Cole D. Yarrington, and Robert Knepper

20th Biennial Conference of the APS Topical Group on
Shock Compression of Condensed Matter,
St. Louis, Missouri,
July 9 – 14, 2017.

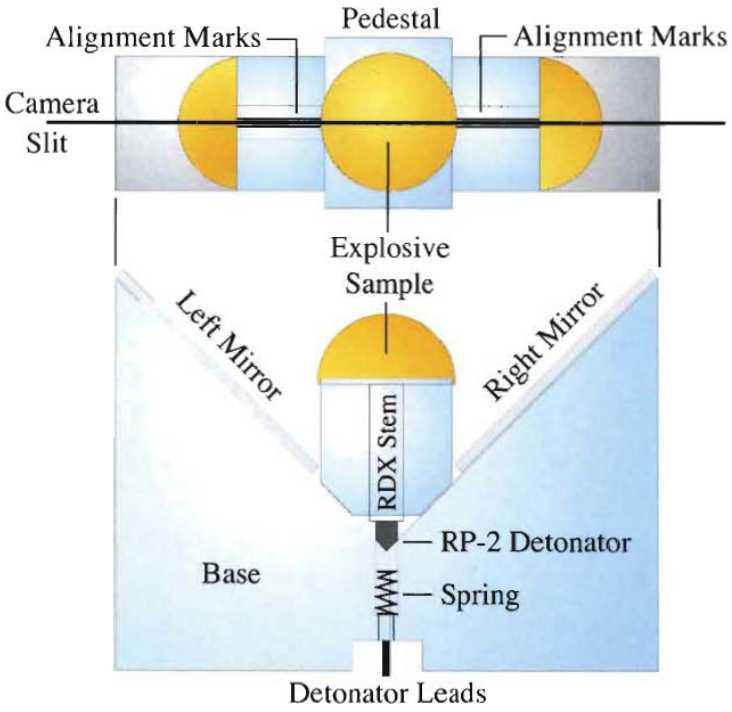
U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.SAND2017-xxxxC.

Introduction

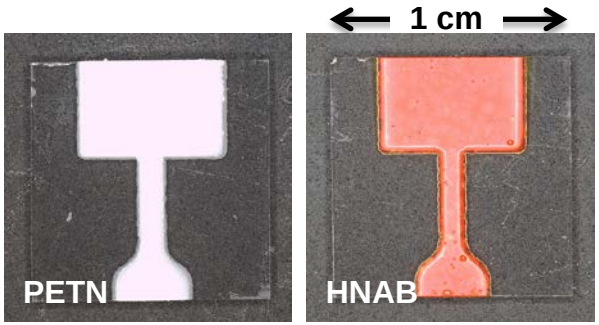
- Detonation corner turning
  - Ability of a detonation wave to propagate into unreacted explosive that is not immediately in the path of the detonation wave
- Dead zone
  - Unreacted explosive outside path of detonation wave
- Mushroom Test (LANL, Larry Hill)
  - Infers detonation corner turning from breakout at the explosive surface
- Motivation: to inform reactive burn models



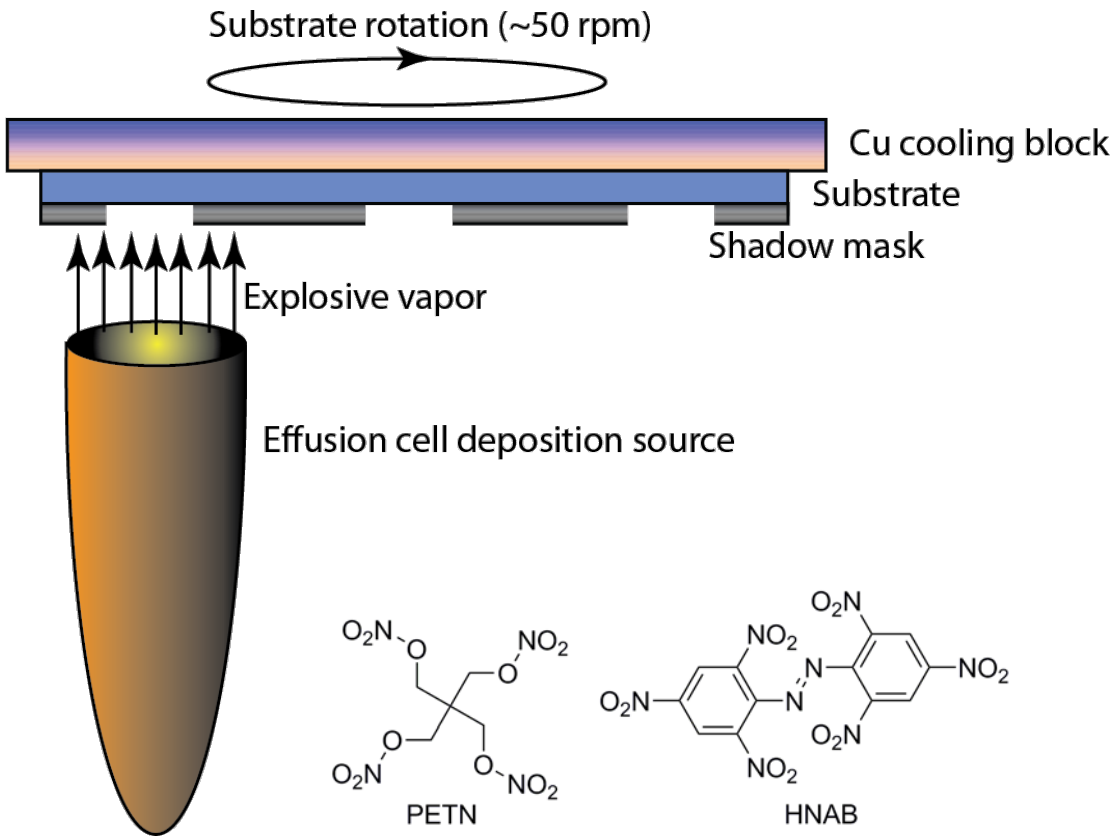
Hill, L. G., W. L. Seitz, et al. (1998). "High explosive corner turning performance and the LANL mushroom test." AIP Conference Proceedings **429**(1): 751-754.

Micromushroom samples
Physical vapor deposition

- Polycarbonate substrates
- PETN and HNAB deposition
- Polycrystalline PETN films
- Amorphous HNAB films



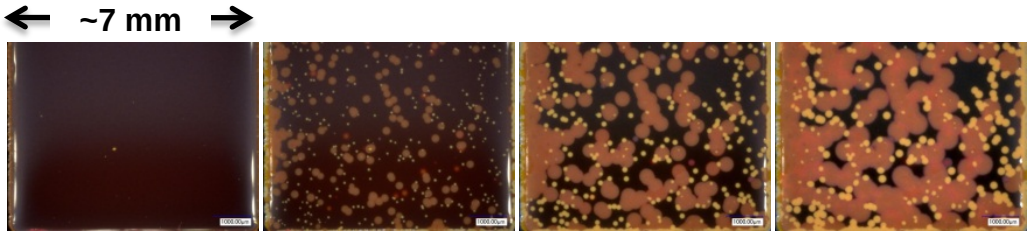
Optical micrographs of deposited HNAB and PETN.



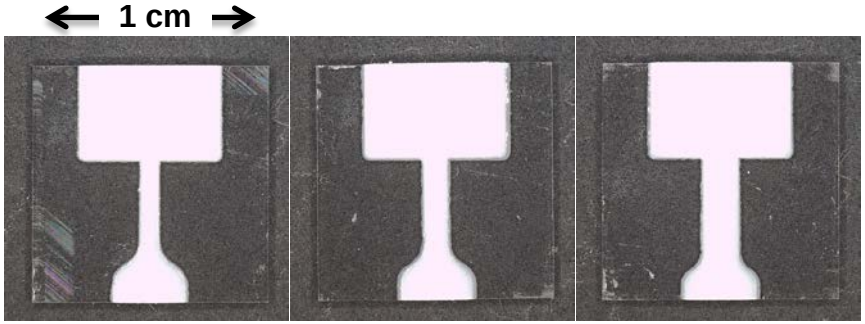
PETN (pentaerythritoltetranitrate)
HNAB (2,2',4,4',6,6'-hexanitroazobenzene)

Micromushroom samples Characteristics

- PETN
  - 173 µm and 277 µm
- HNAB
  - 150 µm, crystallized at 35 ˚C
- Mushroom stem widths
  - 0.75, 1.00, 1.50 mm
- Mushroom cap width
  - 6 mm
- PETN Parylene C coated
- Sylgard® 184 encapsulated with polycarbonate lid to prevent air shock



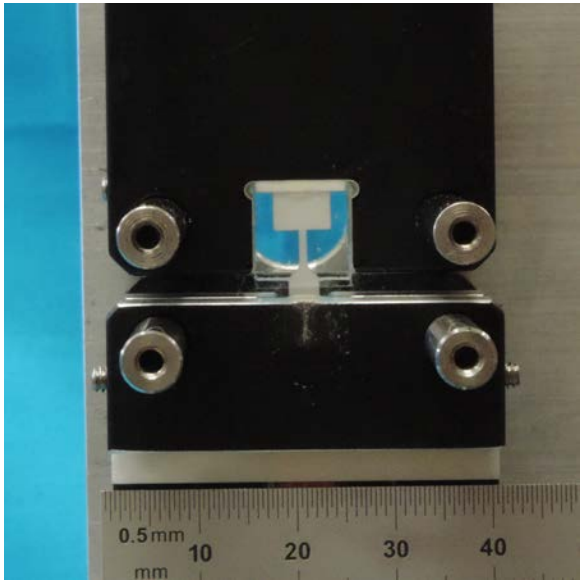
HNAB crystallization, time-lapse 65 °C, 24 min./image.



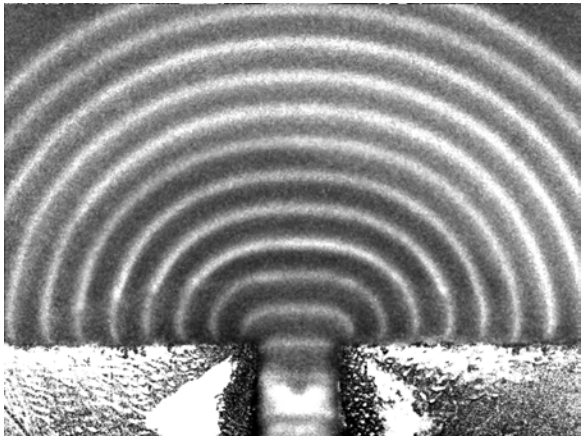
Optical micrographs of deposited PETN with stem widths of 0.75, 1.00, and 1.50 mm.

Micromushroom test

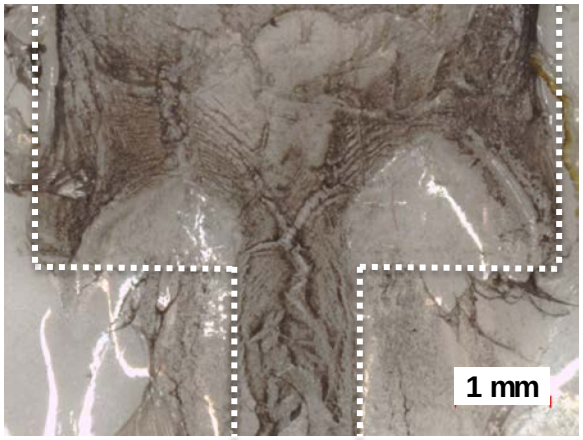
- Optical observation of corner turning
- Framing camera is principal diagnostic



Photograph of micromushroom test with deposited PETN.

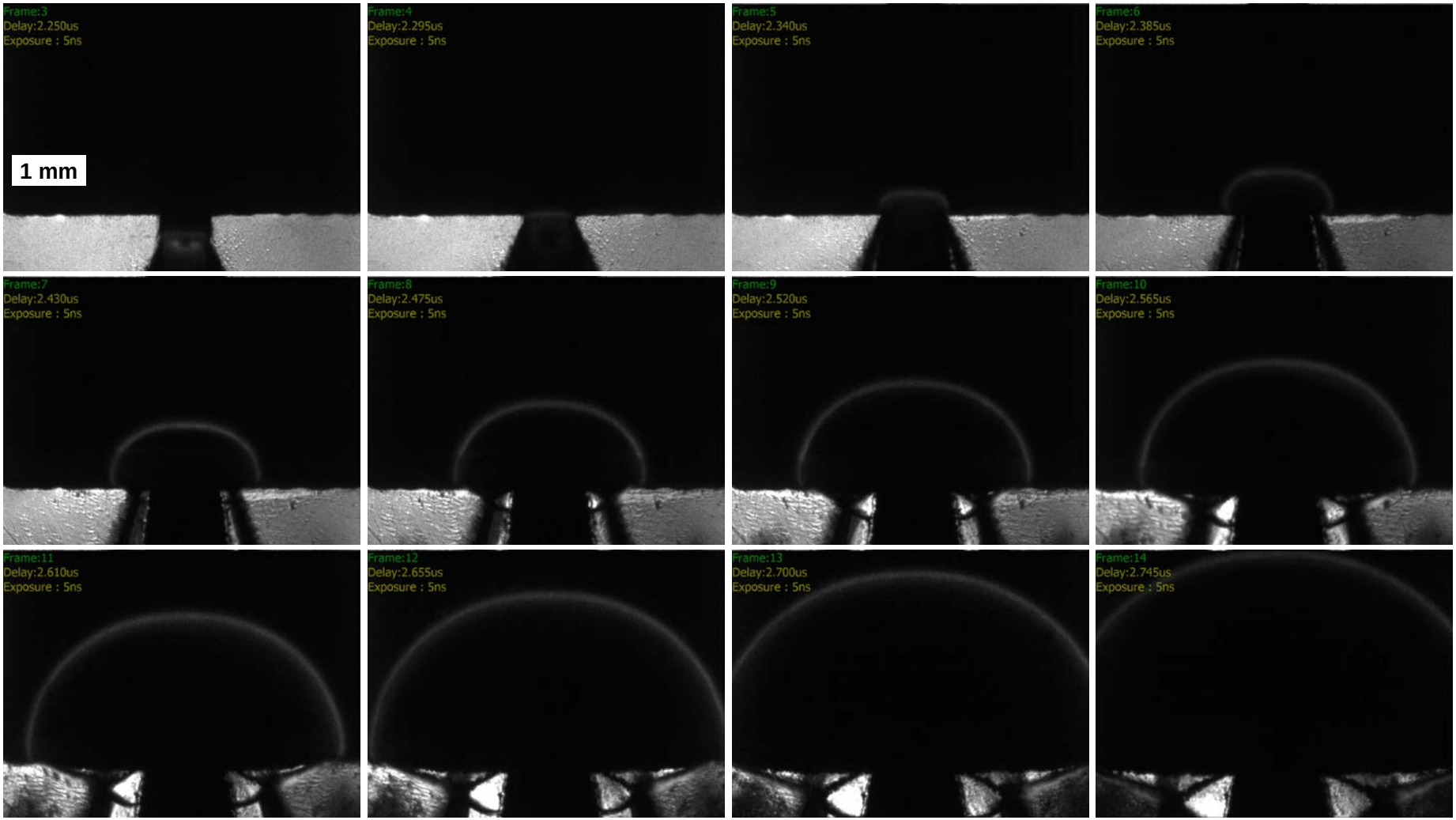


Processed sum of framing camera images, PETN, 5 ns, 22 MHz (1/45 ns).



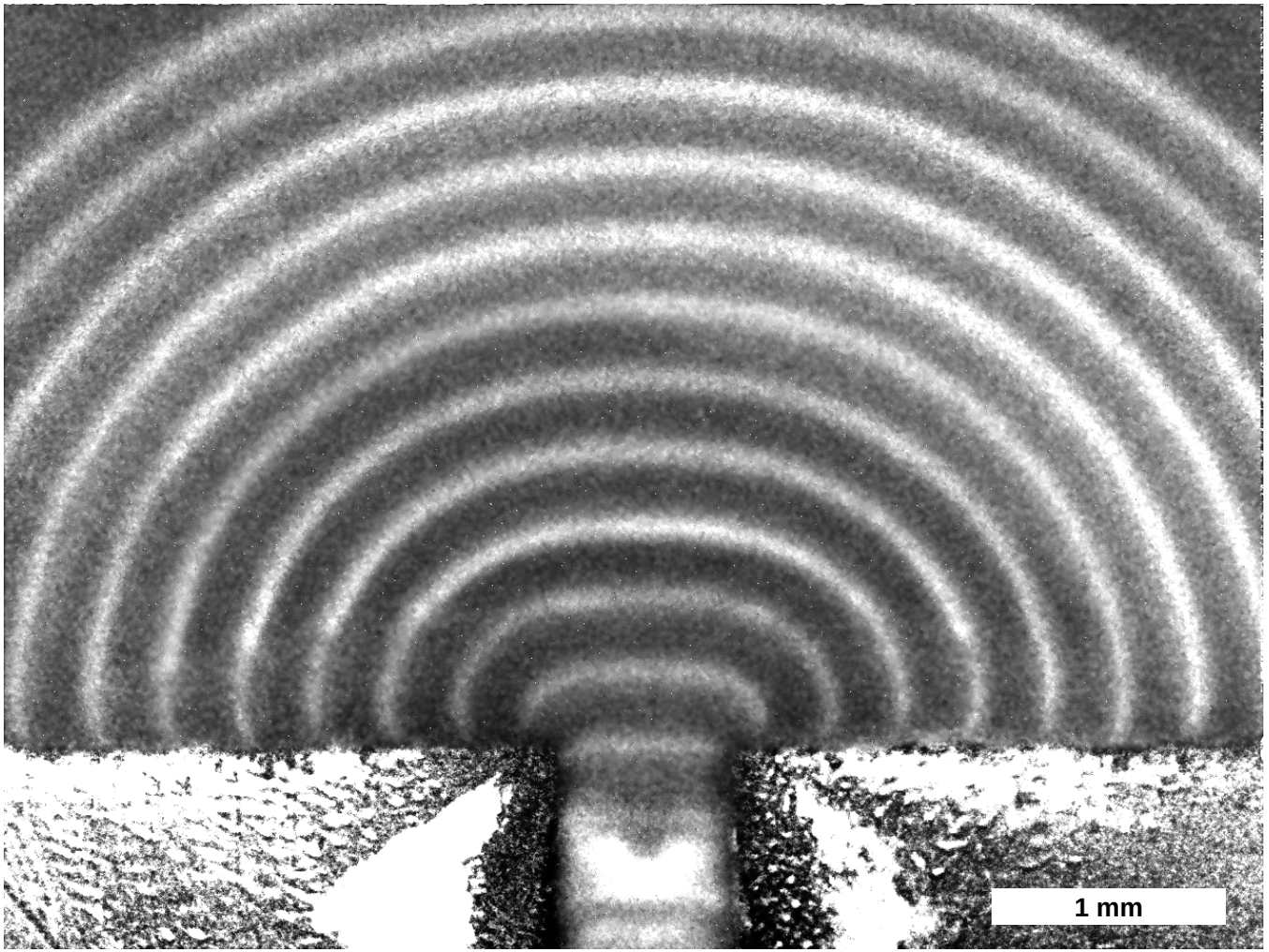
Postmortem image of polycarbonate substrate with HNAB dead zones.

Corner turning, PETN, 0.75 mm stem, 277 µm thick



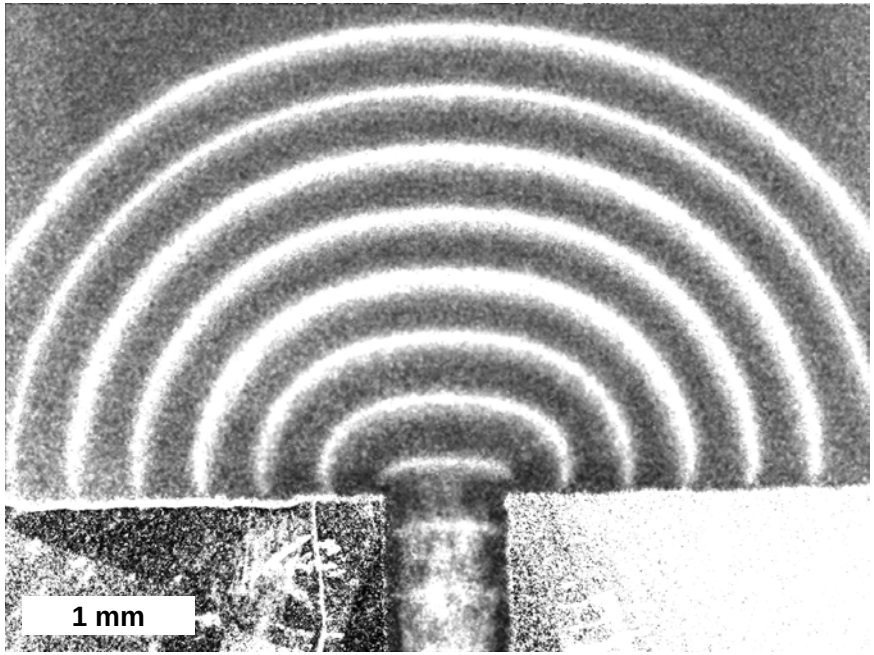
Framing camera images of PETN micromushroom, 5 ns exposure, 22 MHz (1/45 ns).

Corner turning, PETN, 0.75 mm stem, 277 µm thick

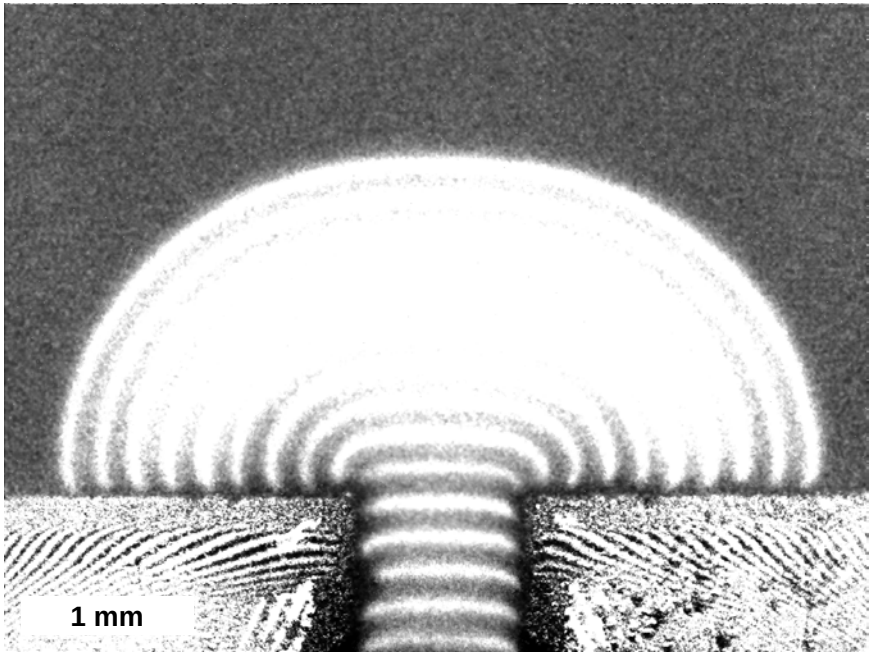


Processed sum of framing camera images, PETN micromushroom, 5 ns exposure, 22 MHz (1/45 ns).

Corner turning, PETN stem width and thickness has little effect



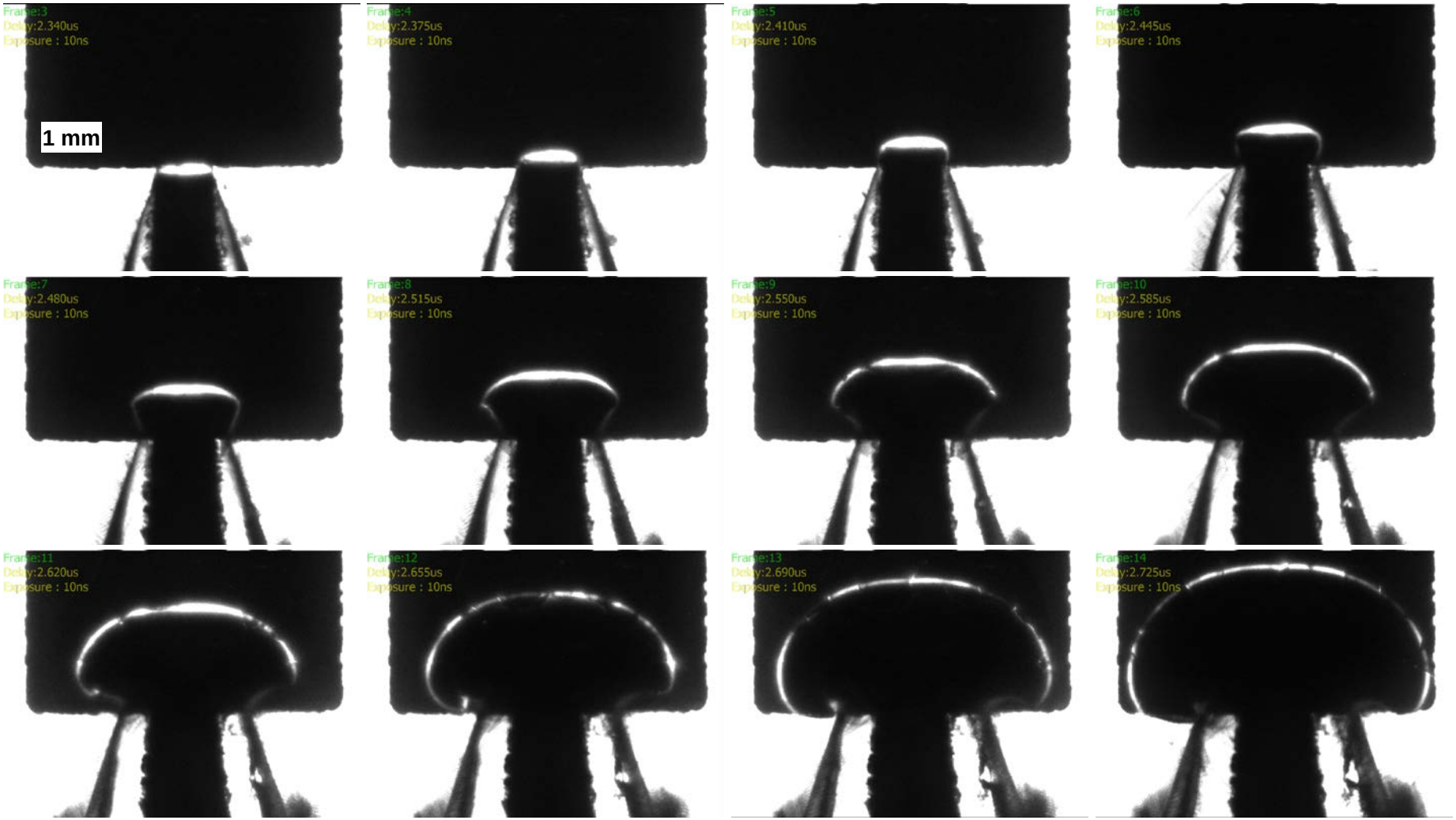
0.75 mm stem width, 173 µm thick.
5 ns exposure, 18 MHz (1/55 ns).



1.00 mm stem width, 277 µm thick.
5 ns exposure, 33 MHz (1/30 ns).

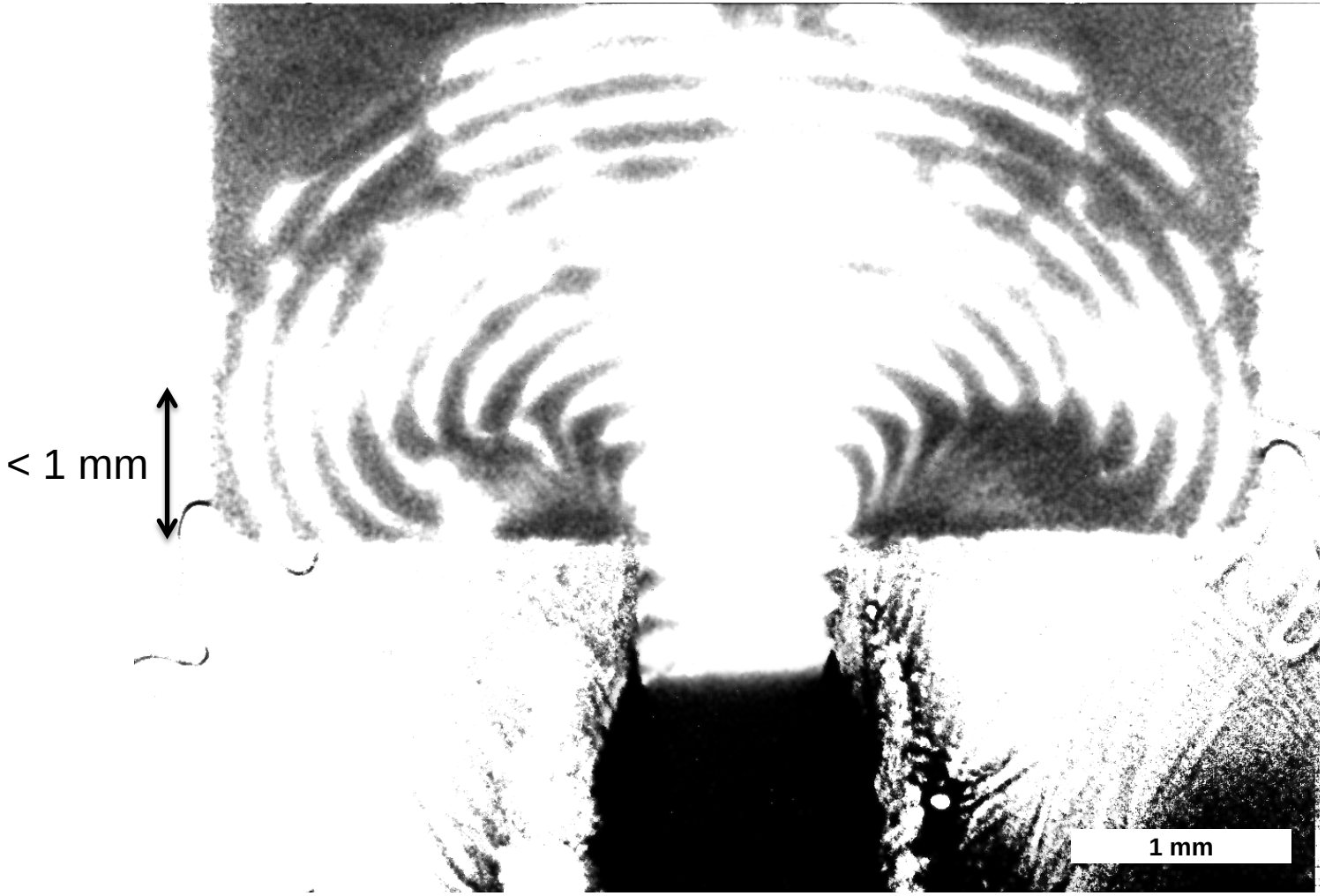
- No measurable corner turning difference in PETN with different stem widths of 0.75 mm, 1.00 mm, and 1.50 mm (1.50 mm not shown) or of different thicknesses.

Corner turning, HNAB, 1.00 mm stem, 150 µm thick



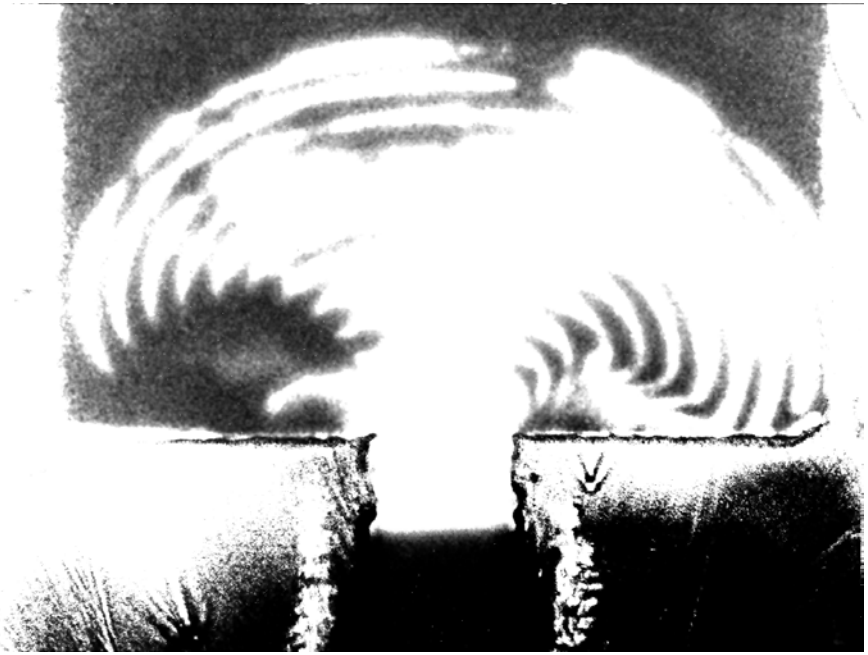
Framing camera images of HNAB micromushroom, 10 ns, 22 MHz (1/45 ns).

Corner turning, HNAB, 1.00 mm stem, 150 µm thick



Processed sum of framing camera images, HNAB micromushroom, 10 ns, 22 MHz (1/45 ns).

Corner turning, HNAB postmortem

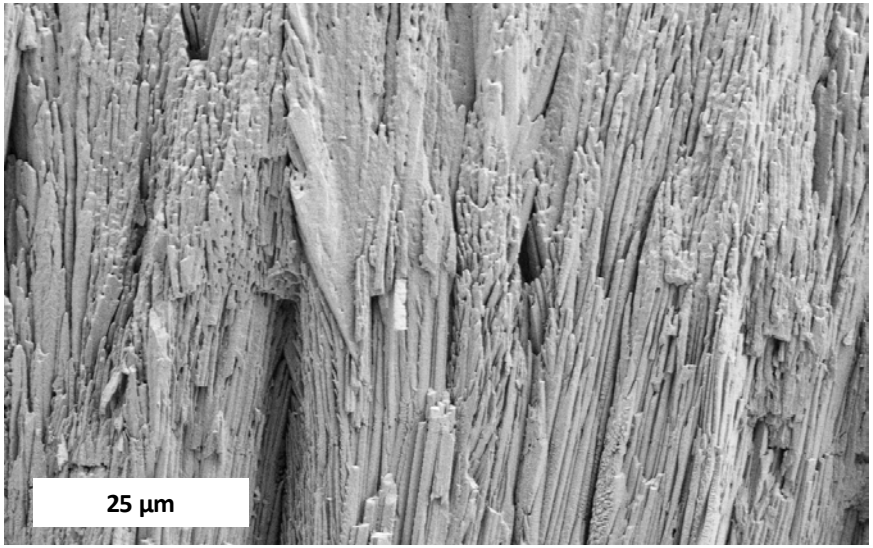


**1.00 mm stem width, 150 μm thick.
5 ns exposure, 22 MHz (1/45 ns).**

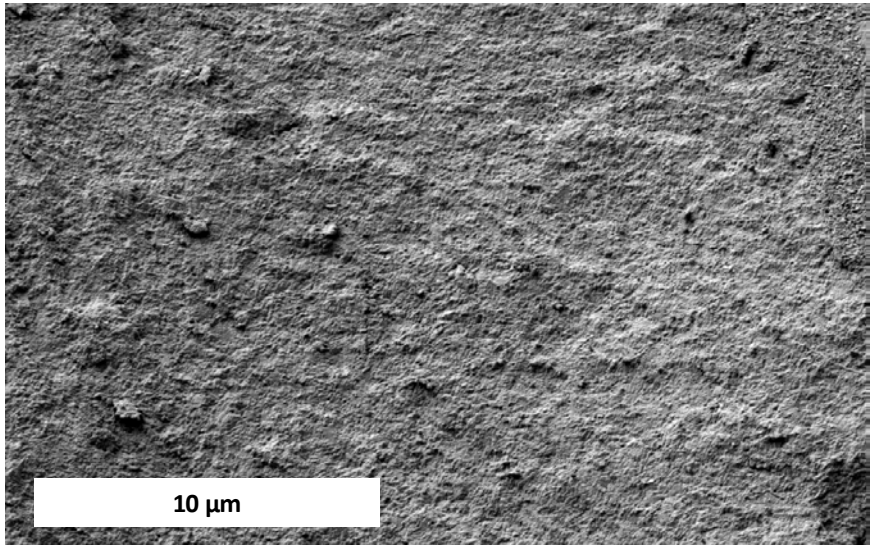
Photograph of polycarbonate substrate, reversed to match framing camera.

- Detonation recorded in polycarbonate substrate (flattened for analysis), showing dead zones

Microstructure and density



PETN scanning electron micrograph, 100 µm wide image.



HNAB scanning electron micrograph, 25 µm wide image.

- PETN, micron-scale grains, 80 – 85% dense
- HNAB, sub-micron-scale grains, 99.5% dense
- Reaction zone of both materials is < 1 µm
- Microstructure affects corner turning

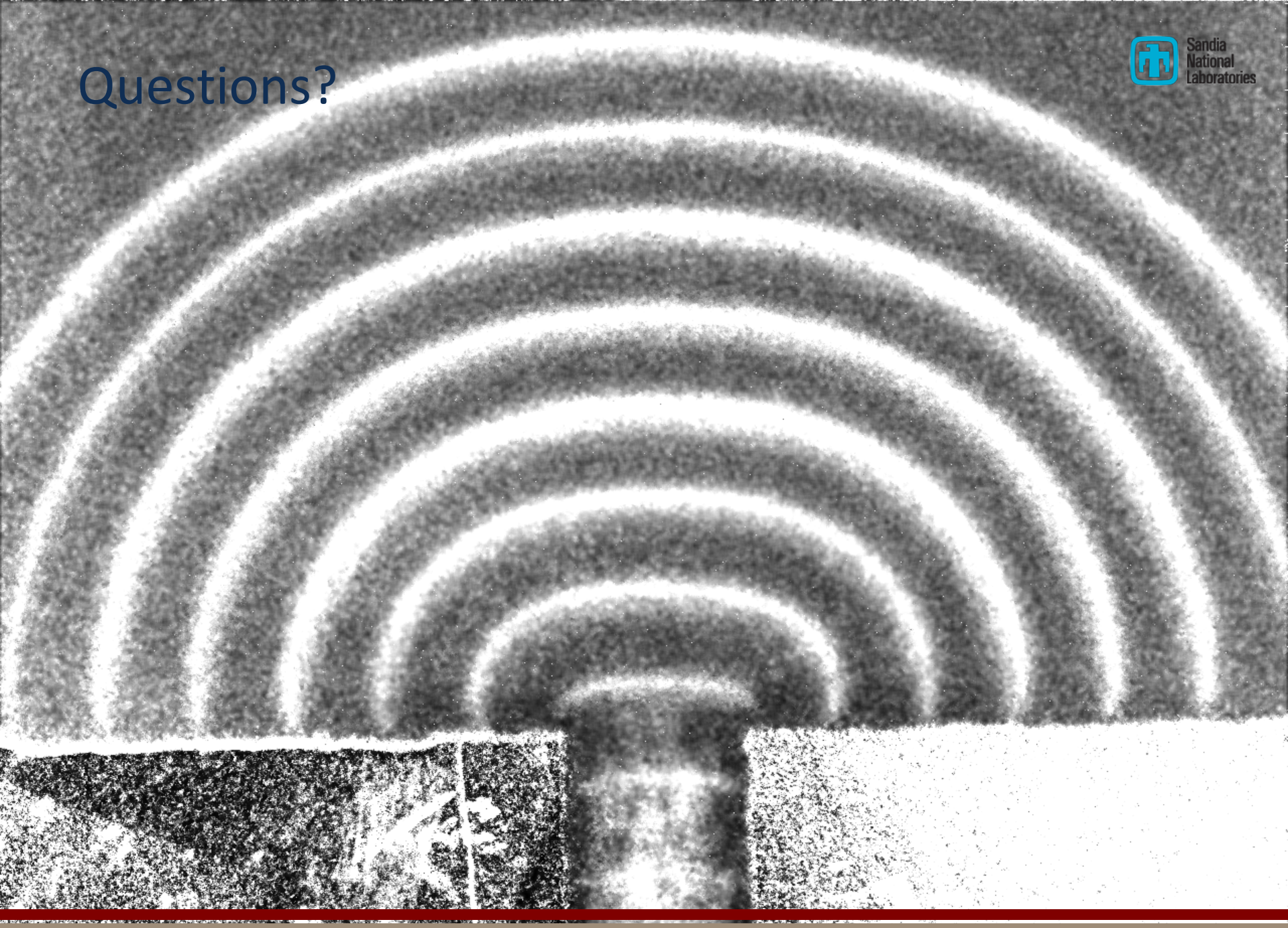
Conclusions

- PETN dead zone is sub-millimeter
  - Films are lower density with micron-sized grains
- HNAB dead zone is ~ 1 mm and highly variable
  - Films are high density with sub-micron-sized grains

- Acknowledgements:
  - Michael P. Marquez, Jon Vasiliauskas
  - Stephen Rupper, Tom Conwell
  - Caitlin O'Grady, James Erikson
  - M. Barry Ritchey

- Funding:
  - Sandia's Laboratory Directed Research and Development Program
  - Joint Department of Defense/Department of Energy Munitions Technology Development Program

Questions?



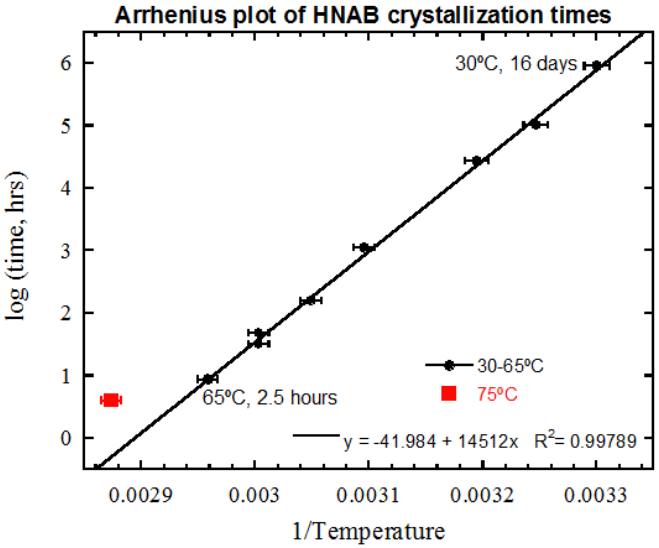
Sandia National Laboratories

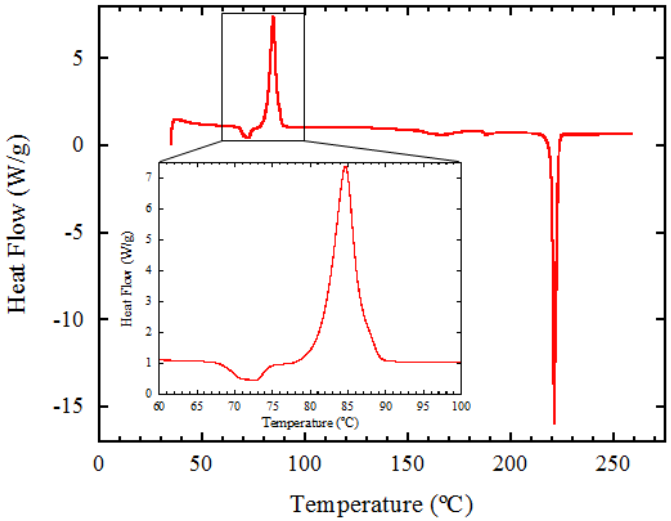
Backup slides

Sandia National Laboratories

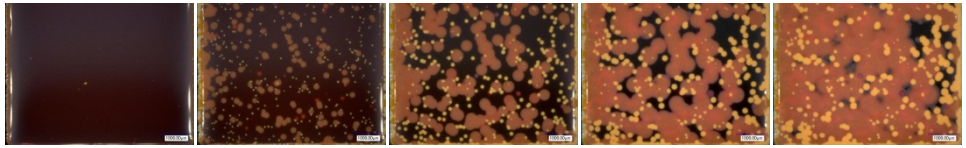
HNAB crystallization

- Amorphous HNAB films crystallize over time
- Pronounced difference in crystallization above glass transition temperature (T_g, ~70 °C)





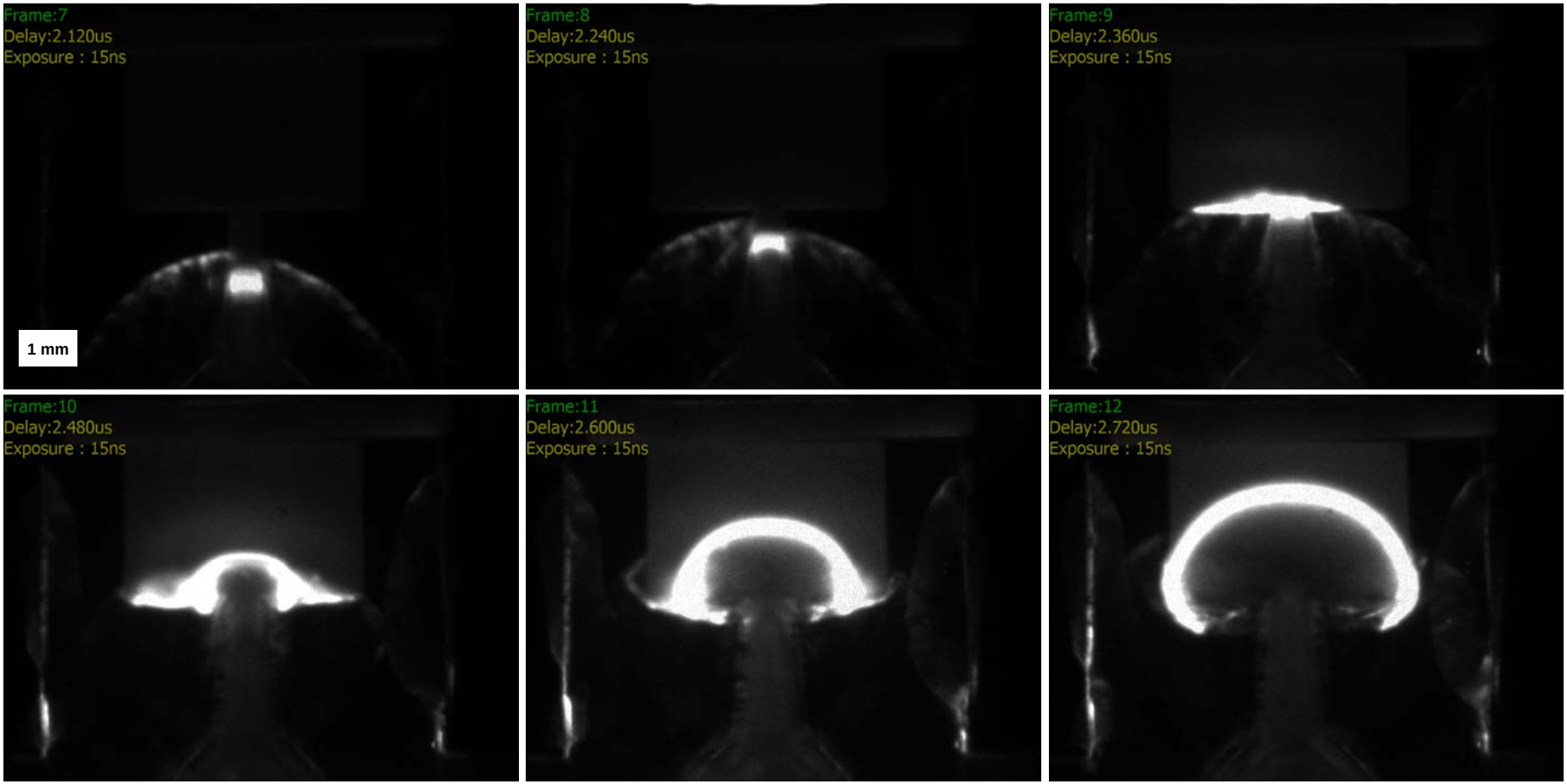
DSC data from an amorphous HNAB film heated from 40–250 °C at 5 °C/min.



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

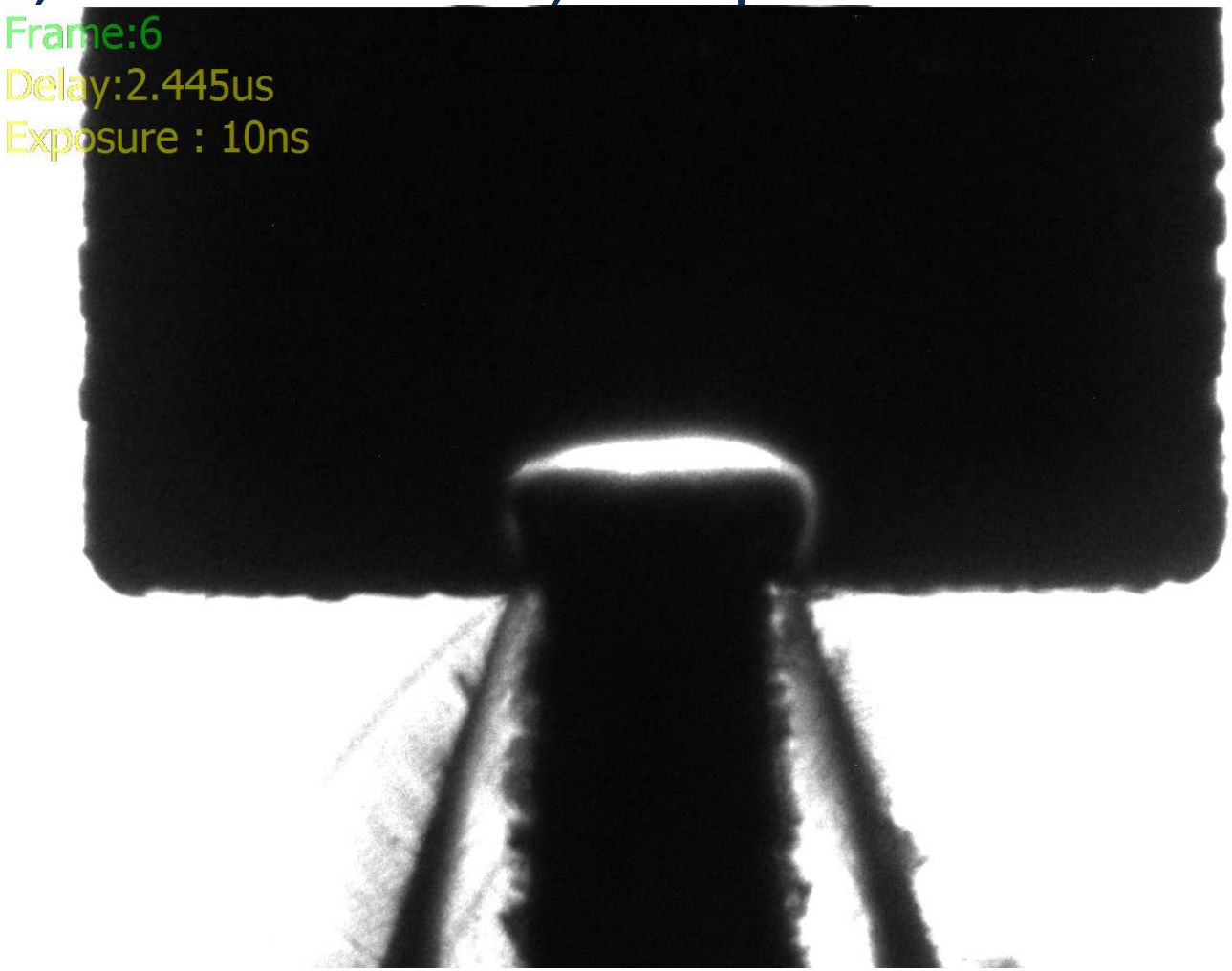
Knepper, R., Browning, K., Wixom, R.R., Tappan, A.S., Rodriguez, M.A., and Alam, M.K., "Microstructure Evolution during Crystallization of Vapor-Deposited Hexanitroazobenzene Films," *Propellants, Explosives, Pyrotechnics*, vol. 37, pp. 459 – 467, 2012.

Air shock preceding detonation wave



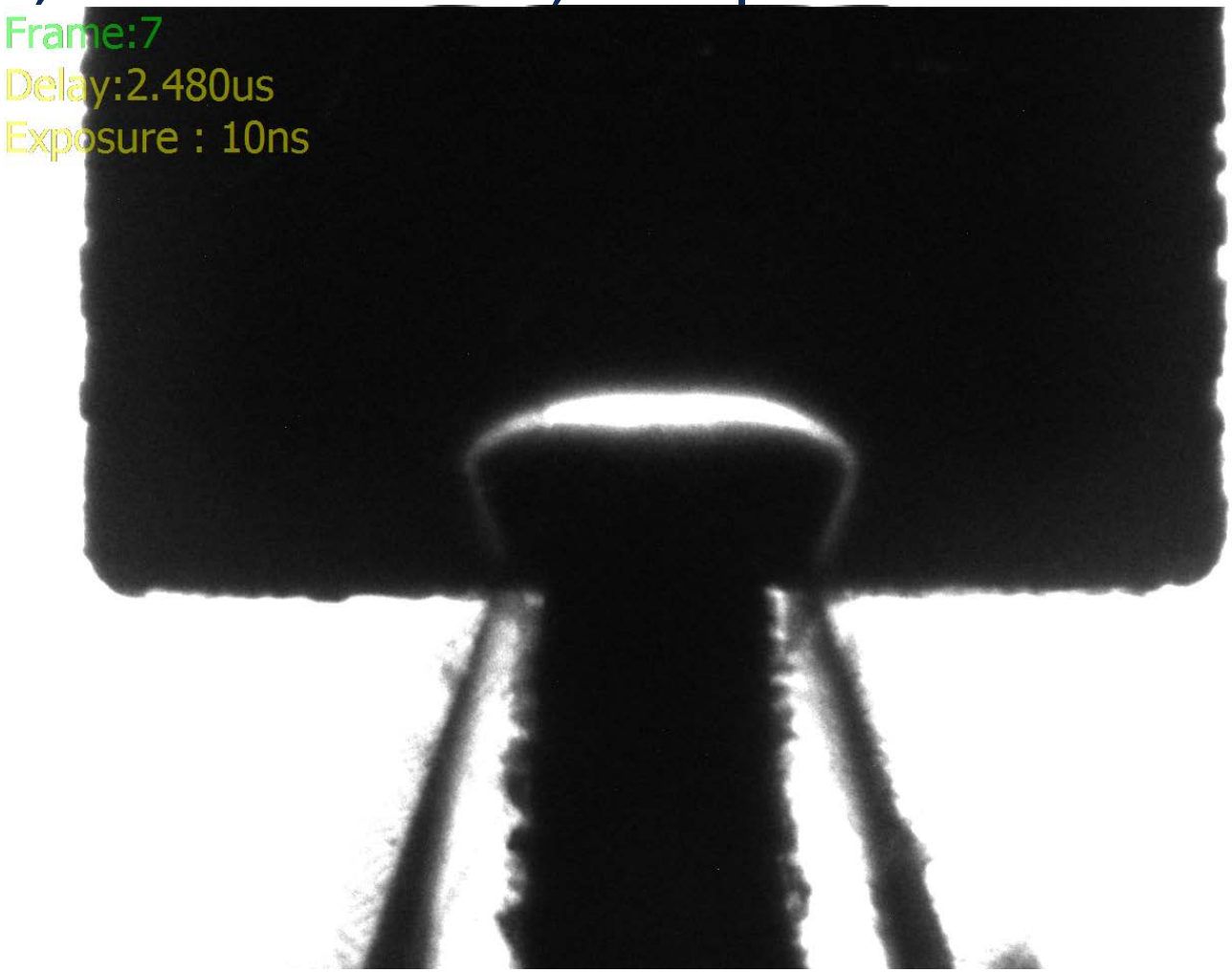
Framing camera images of PETN micromushroom, 15 ns, 8.3 MHz (1/120 ns). Some effect seen on corner turning. Possible dead-pressing.

Corner turning, HNAB, 1.00 mm stem, 150 µm thick



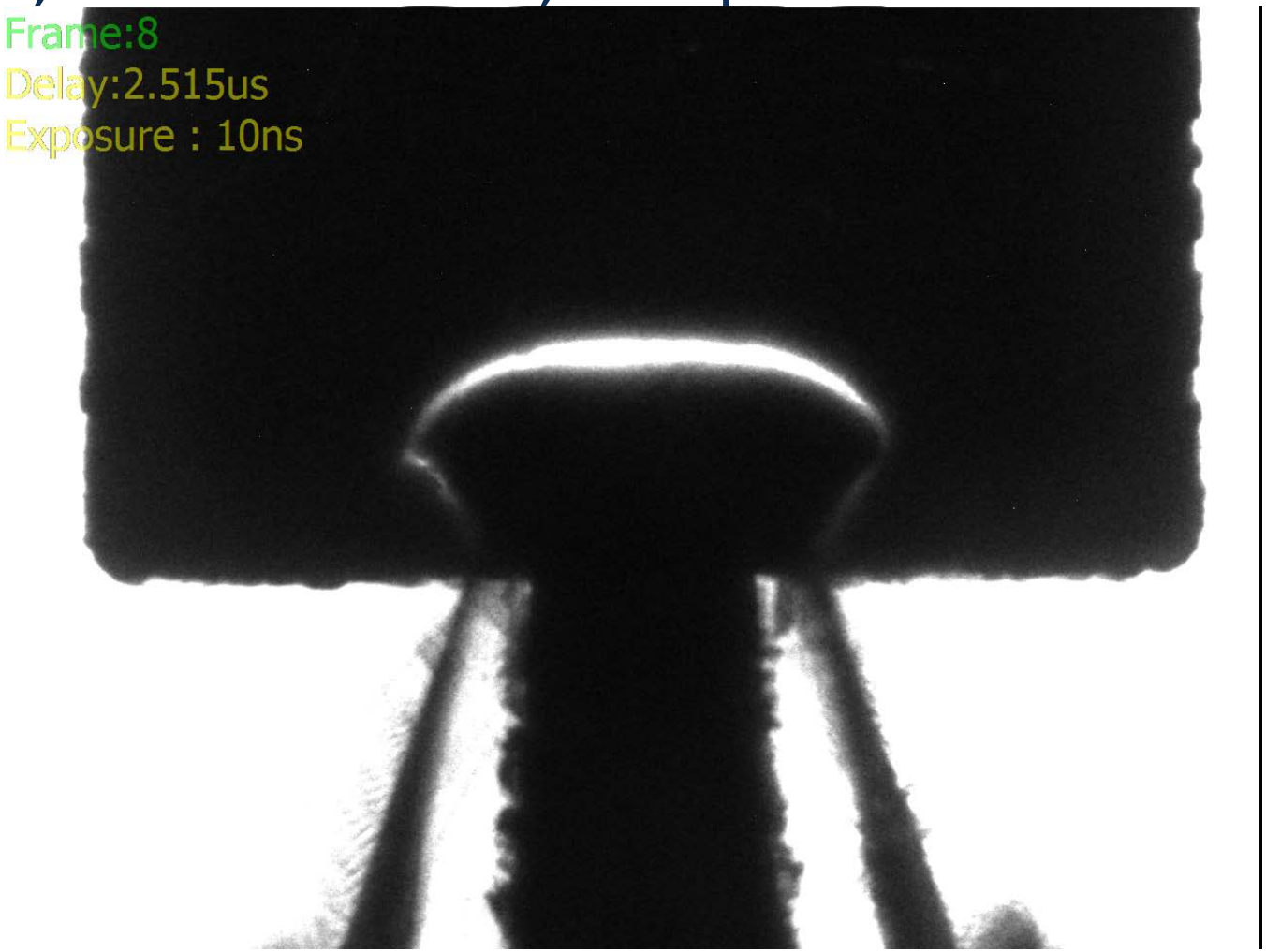
Framing camera images of HNAB micromushroom, 10 ns, 22 MHz (1/45 ns).

Corner turning,
HNAB, 1.00 mm stem, 150 µm thick



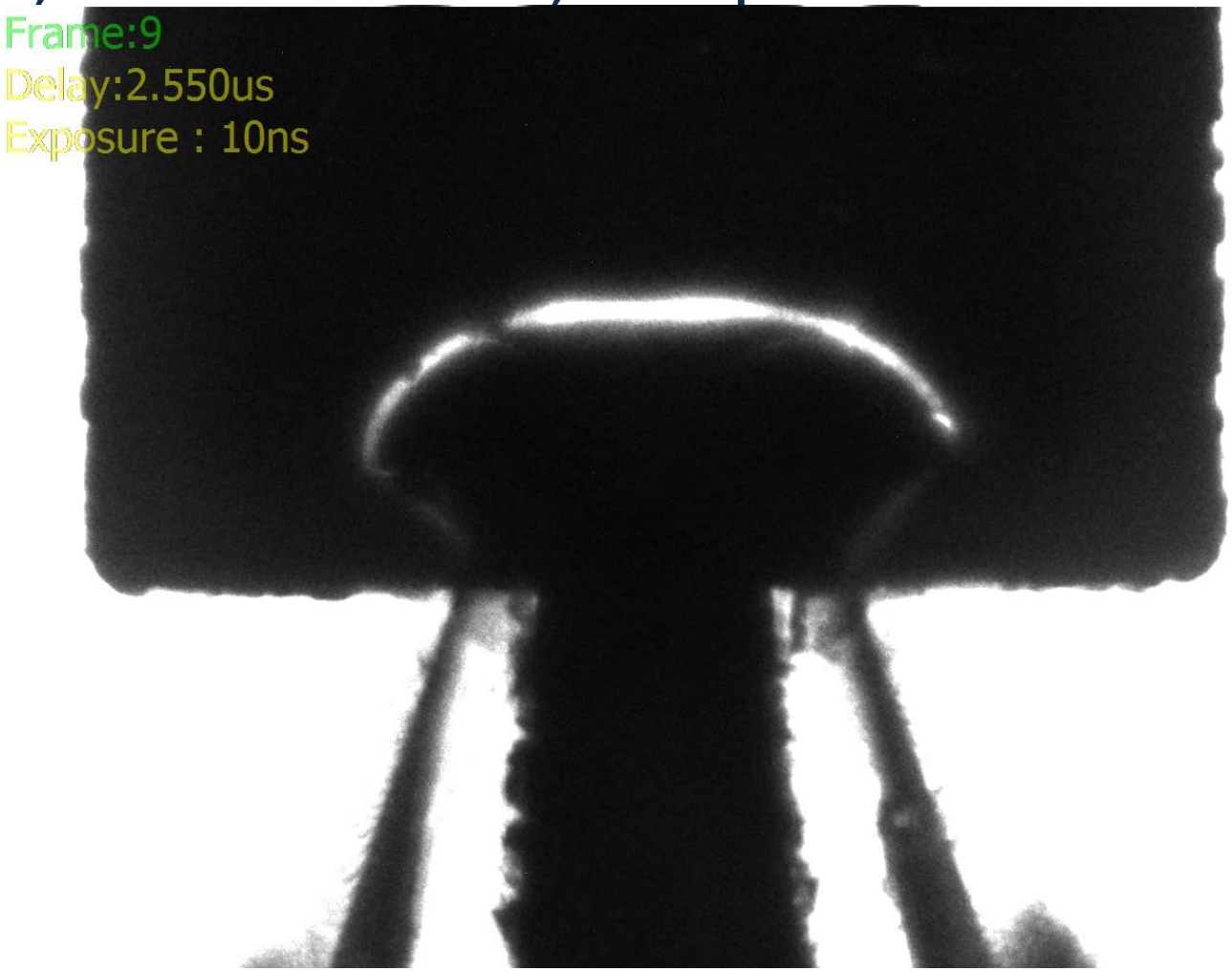
Framing camera images of HNAB micromushroom, 10 ns, 22 MHz (1/45 ns).

Corner turning,
HNAB, 1.00 mm stem, 150 µm thick



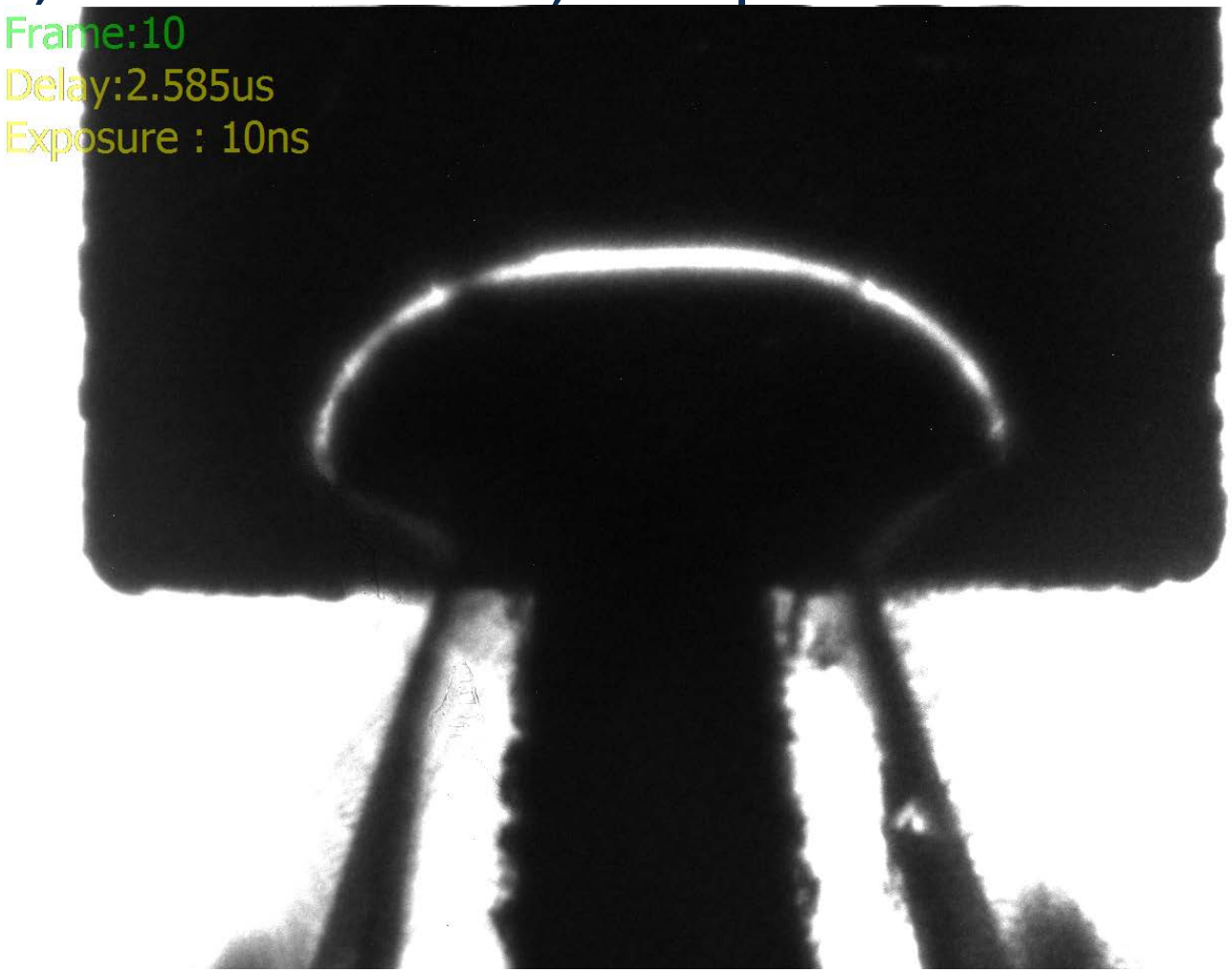
Framing camera images of HNAB micromushroom, 10 ns, 22 MHz (1/45 ns).

Corner turning, HNAB, 1.00 mm stem, 150 µm thick



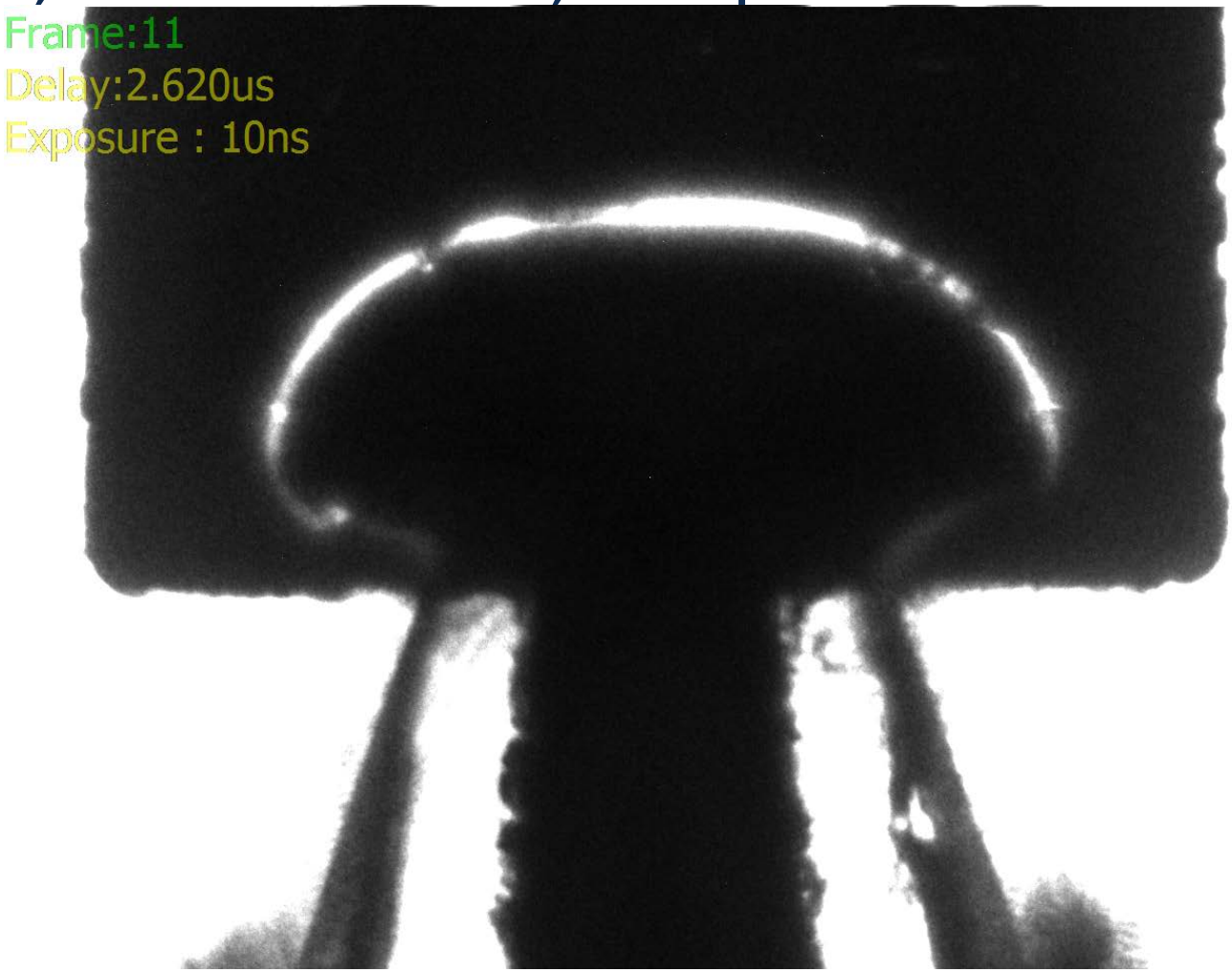
Framing camera images of HNAB micromushroom, 10 ns, 22 MHz (1/45 ns).

Corner turning, HNAB, 1.00 mm stem, 150 µm thick



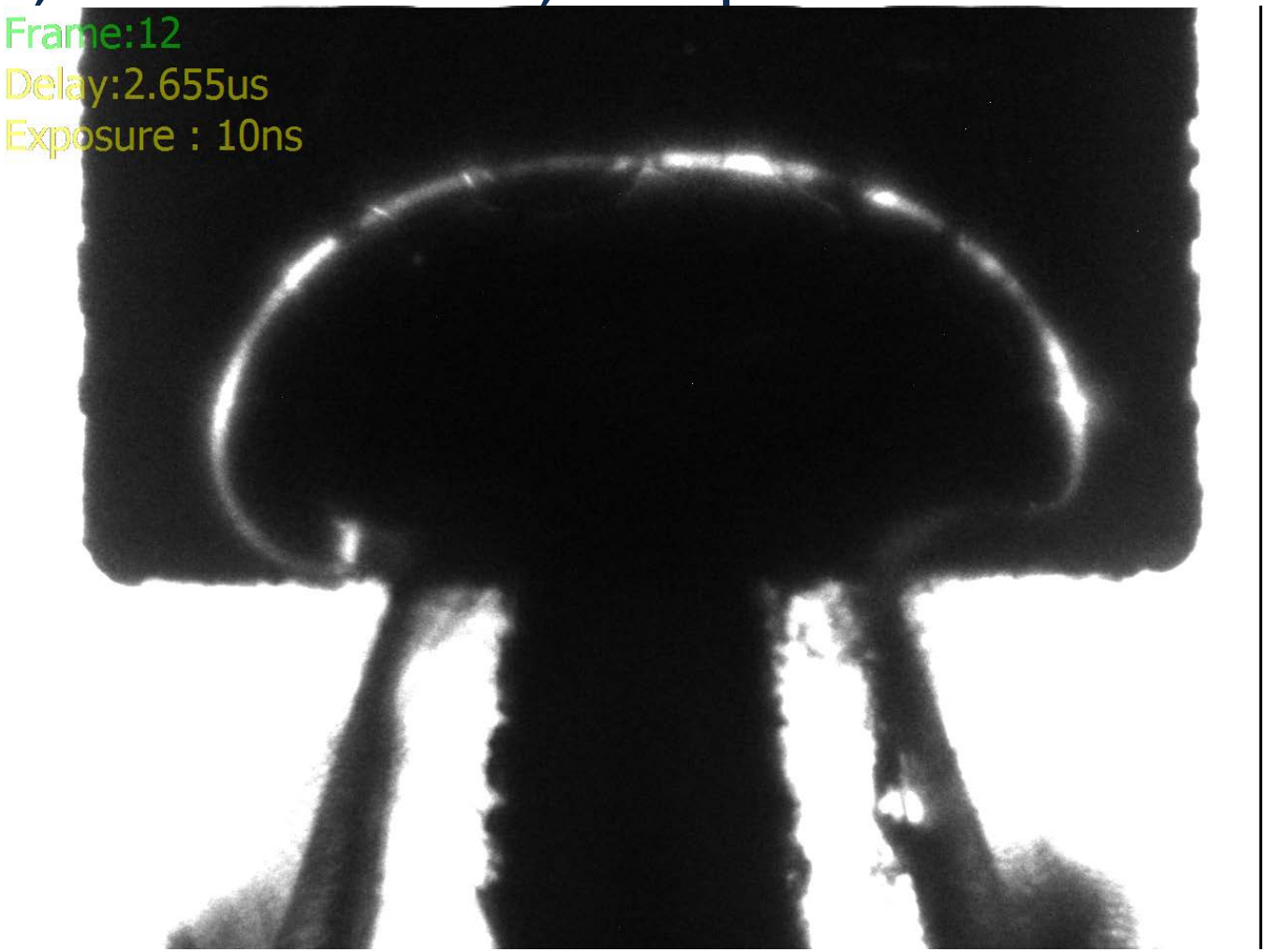
Framing camera images of HNAB micromushroom, 10 ns, 22 MHz (1/45 ns).

Corner turning,
HNAB, 1.00 mm stem, 150 µm thick



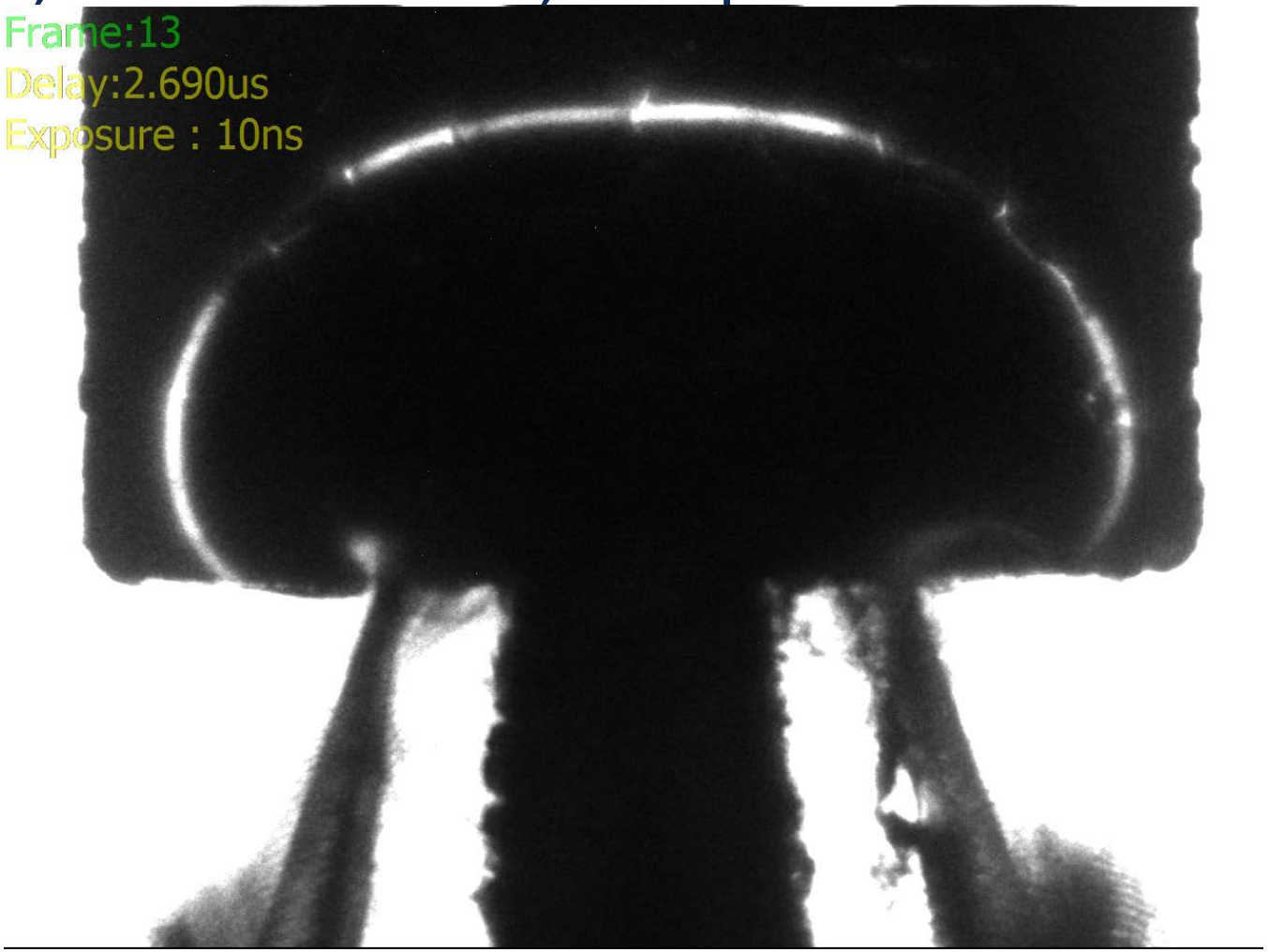
Framing camera images of HNAB micromushroom, 10 ns, 22 MHz (1/45 ns).

Corner turning, HNAB, 1.00 mm stem, 150 µm thick



Framing camera images of HNAB micromushroom, 10 ns, 22 MHz (1/45 ns).

Corner turning, HNAB, 1.00 mm stem, 150 µm thick



Framing camera images of HNAB micromushroom, 10 ns, 22 MHz (1/45 ns).

Corner turning, HNAB, 1.00 mm stem, 150 µm thick

Framing camera images of HNAB micromushroom, 10 ns, 22 MHz (1/45 ns).