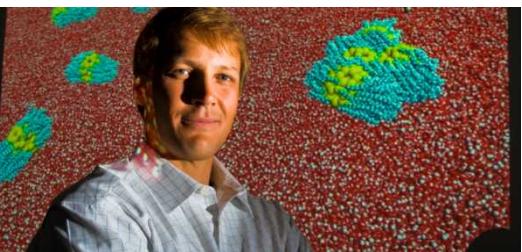


NANO-SURFACE FINISHING FOR ELECTROTHERMAL INSTABILITY EVOLUTION STUDIES

SAND2016-9860C



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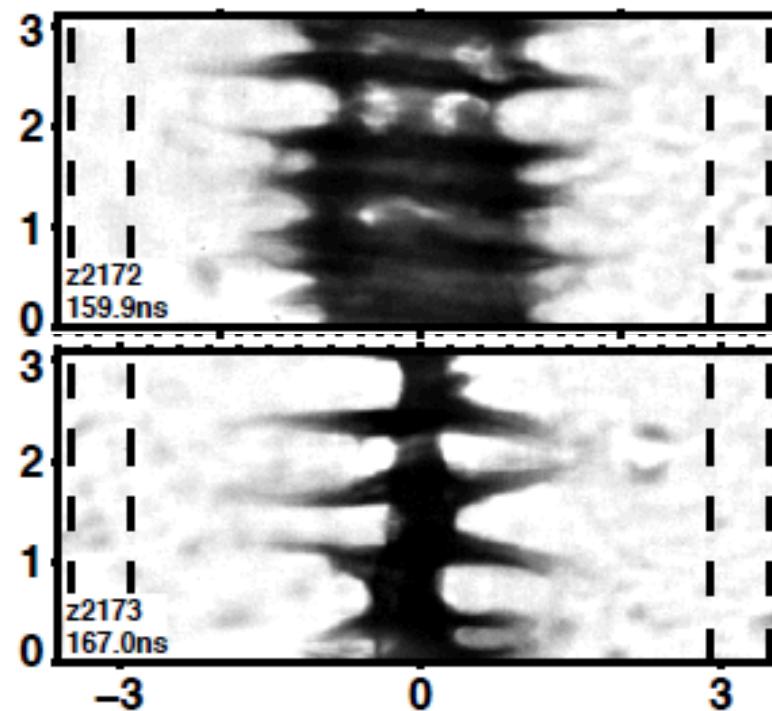
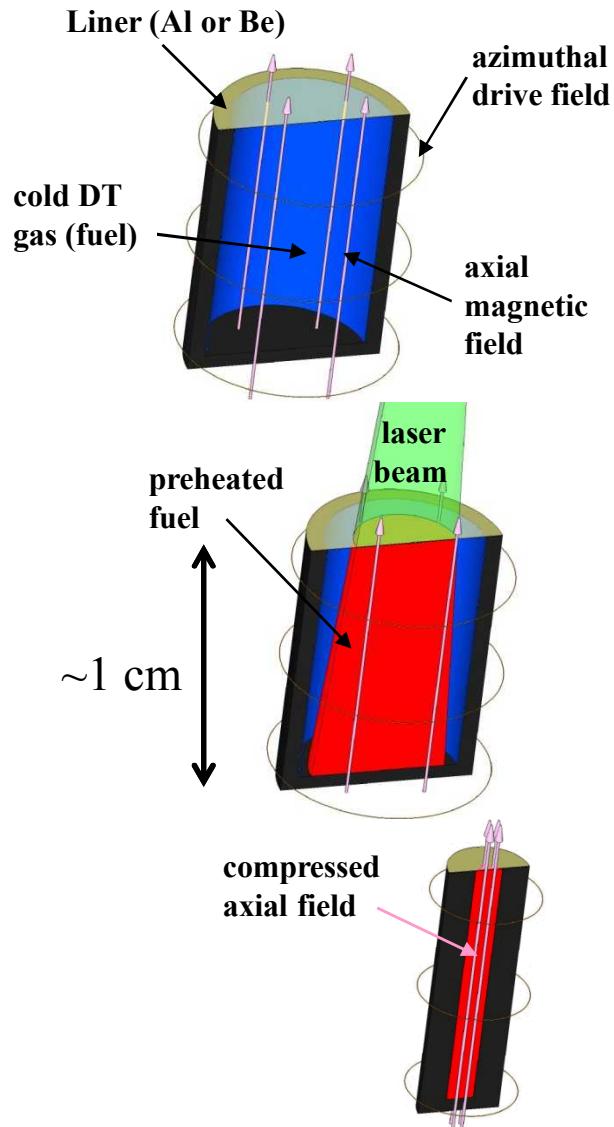


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Alignment to First to High Yield Fusion RC Roadmap:

- Roadmap goal is to achieve controlled fusion in the laboratory by 2035 with a fusion yield of at least 1 gigajoule per pulse.
- Controlled fusion in the laboratory is a grand, cross-cutting scientific challenge. Success will depend strongly on our ability to model complex systems on high performance computer platforms.
- The MagLIF fusion target concept reduces the pressures required to achieve fusion by magnetizing and pre-heating the fusion fuel.

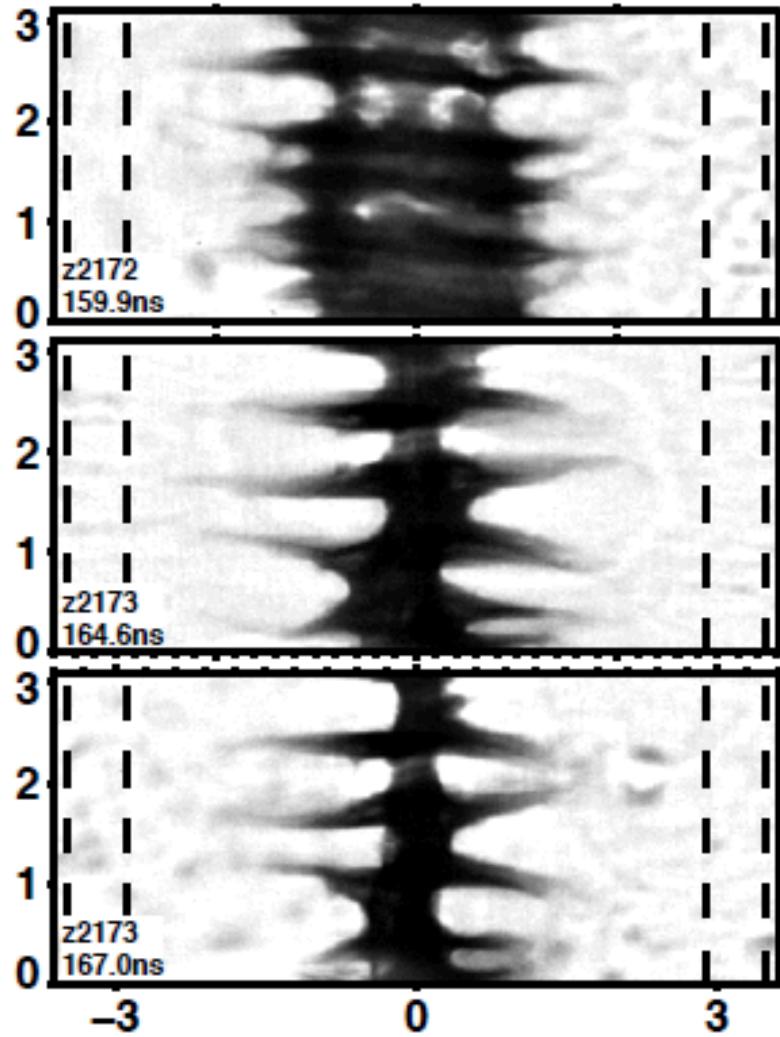
MagLIF: Fuel pre-heat & magnetization allow relatively slow implosions to achieve significant fusion yield



“The magneto-Rayleigh-Taylor MRT instability poses the greatest threat to this (MagLIF) approach to fusion.”

S.A. Slutz *et al.*, Phys. Plasmas 17, 056303 (2010);

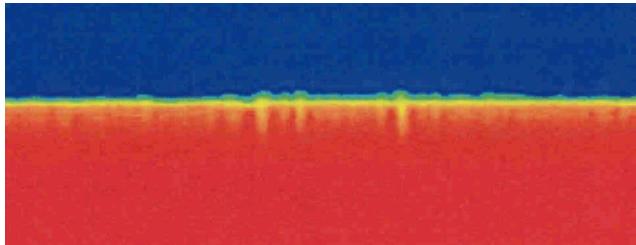
The Magneto-Raleigh-Taylor (MRT) instability can destroy the implosion symmetry required for fuel compression and inertial confinement



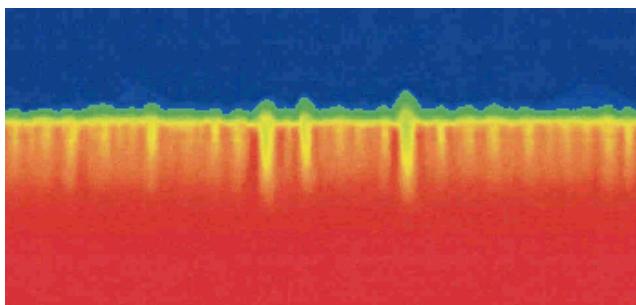
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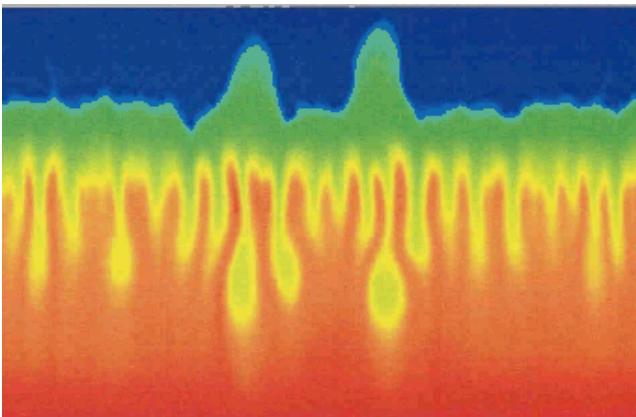
2D simulations show electro-thermal instabilities (ETI) develop after melt and seed later MRT growth



Due to non-uniformities in the metal's initial resistivity, as the metal surface melts, electrothermal instabilities grow rapidly



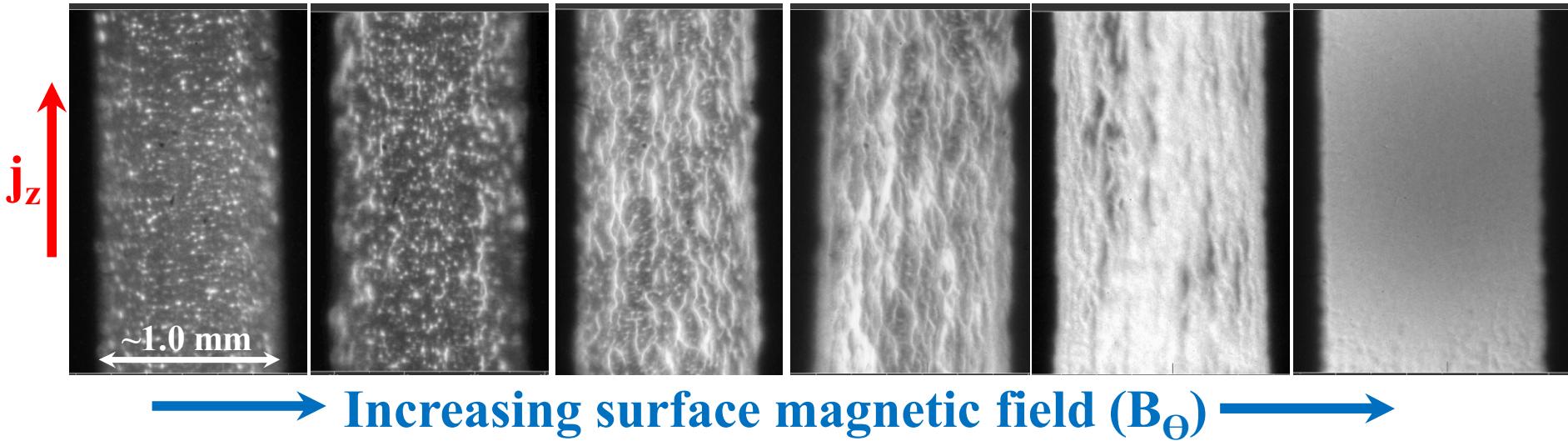
The Magneto-Raleigh Taylor (MRT) instability grows from the ETI seed, and begins to dominate



Non-linear MRT growth redistributes liner mass; large amplitude perturbations persist and grow

K.J. Peterson *et al.*, Phys. Plasmas **19**, 092701 (2012).
K.J. Peterson *et al.*, Phys. Plasmas **20**, 056305 (2013).
K.J. Peterson *et al.*, accepted, *Physical Review Letters*

High-resolution (10 μm , 2 ns) images of visible light emission from solid metal targets show complex and non-uniform structure as plasma forms on the surface

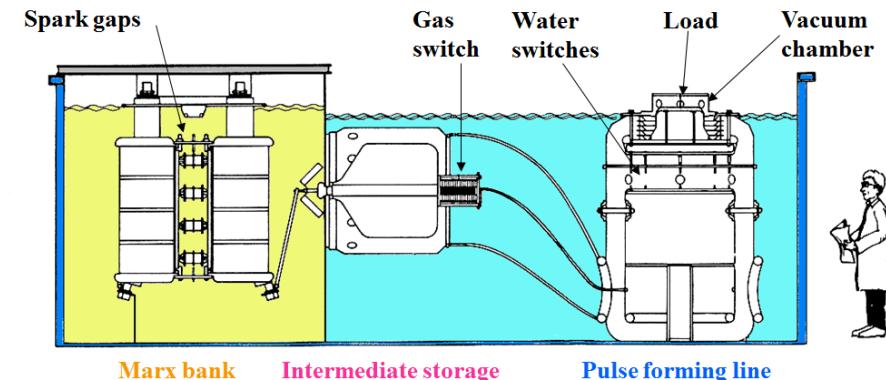


Targets were 1-mm diameter aluminum rods pulsed using $B_\theta \sim 3 \text{ MG}$ in 100 ns on the ZEBRA pulsed power facility at the University of Nevada-Reno

Our **approach** leverage previous work; we added advanced target fabrication and characterization and improved diagnostics

U of Nevada, Reno Zebra Facility

- 100 ns rise time (similar to Z)
- Suite of low temperature (NIR to EUV) diagnostics suitable for ETI studies
- **Up to 5 shots per day.**

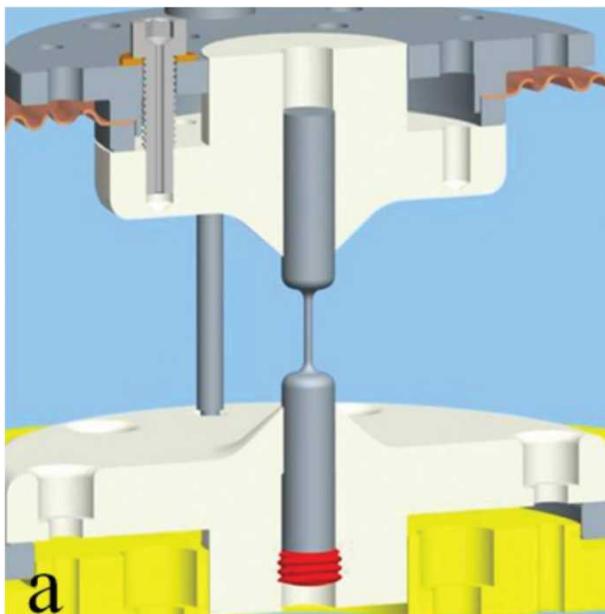


The “barbell load in knife-edge hardware” is **carefully designed to avoid non-thermal plasma formation mechanisms** common to high-voltage generators

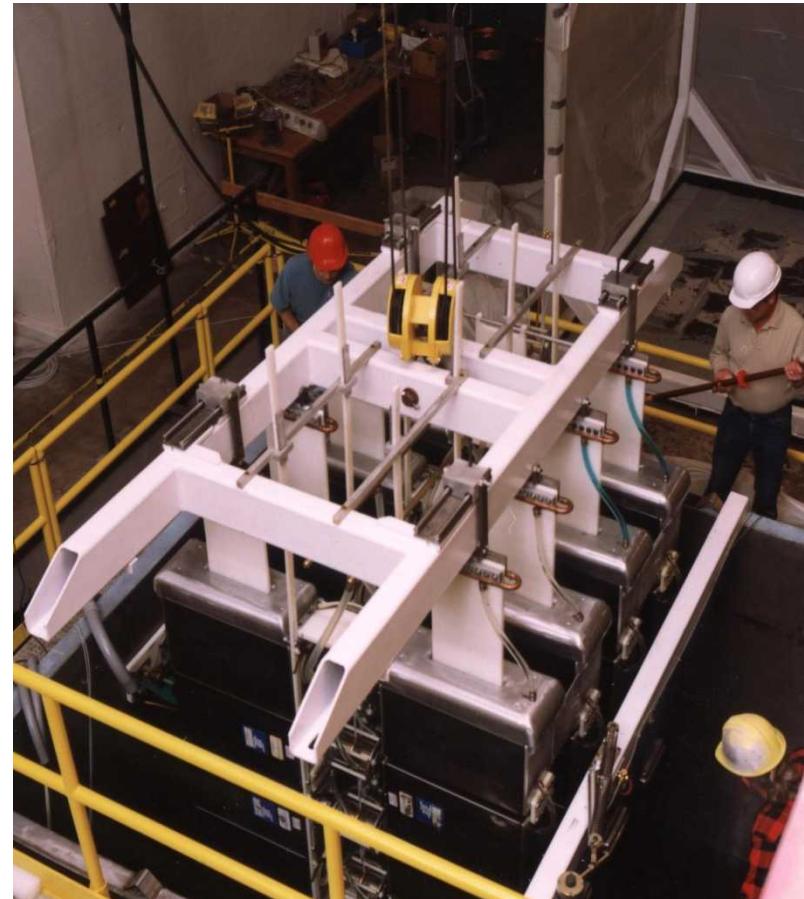
T.J. Awe, B.S. Bauer, S. Fuelling, and R.E. Siemon. Phys. Rev. Lett. **104**, 035001 (2010).

T.J. Awe, B.S. Bauer, S. Fuelling, I.R. Lindemuth, R.E. Siemon. Phys. Plasmas **17**, 102507 (2010).

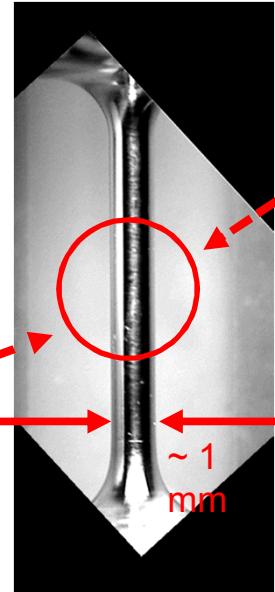
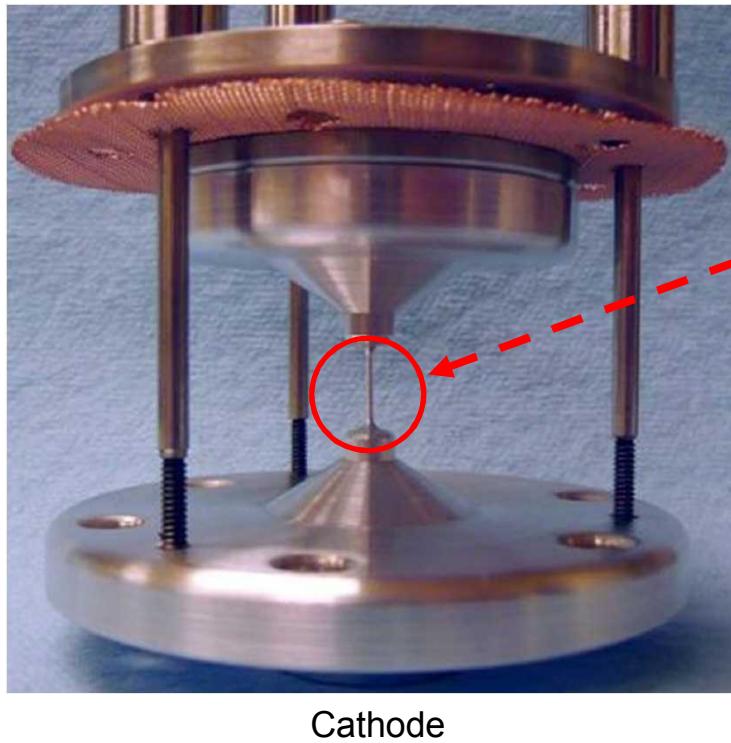
T.J. Awe, B.S. Bauer, S. Fuelling, and R.E. Siemon. Phys. Plasmas **18, 056304 (2011).**



Experiment on 1-MA/100-ns Zebra (UNR) studies plasma formed by multi-Megagauss (MG) field pulsed on metals



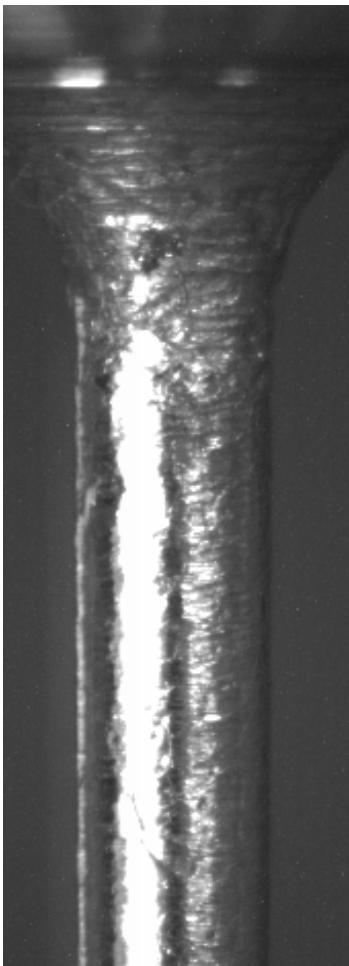
Load hardware reproducibly mitigates non-thermal breakdown



Buried knife-edge contacts mitigate arcing/break oxide layer, and smooth cathode transitions inhibit avalanche breakdown.

Advance target fabrication techniques allow ETI to be the dominant seed for MRT

UNR-Machined
Barbell load



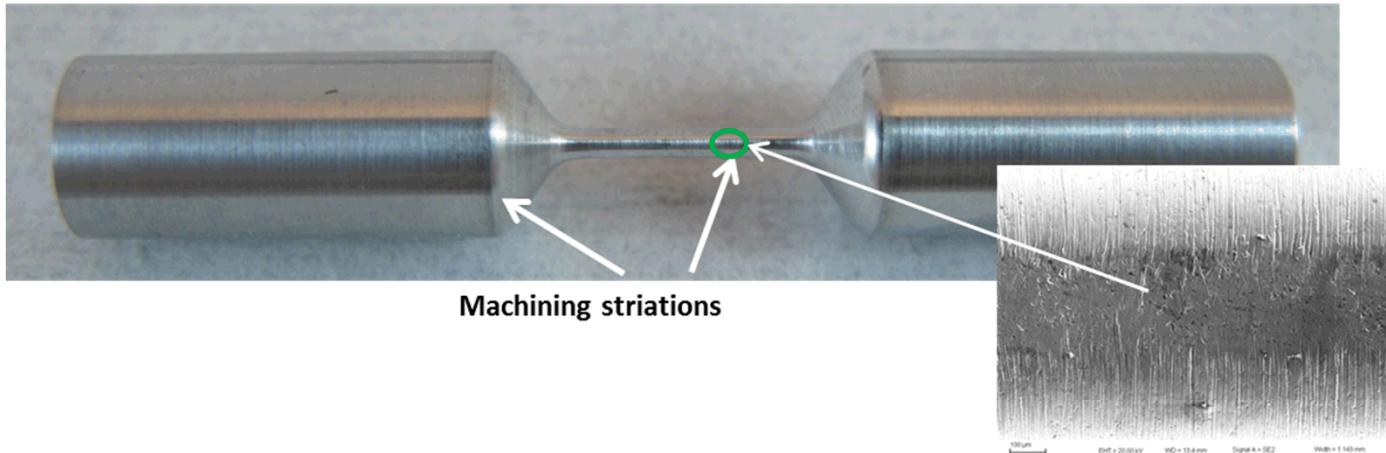
Diamond turned
MagLIF liner



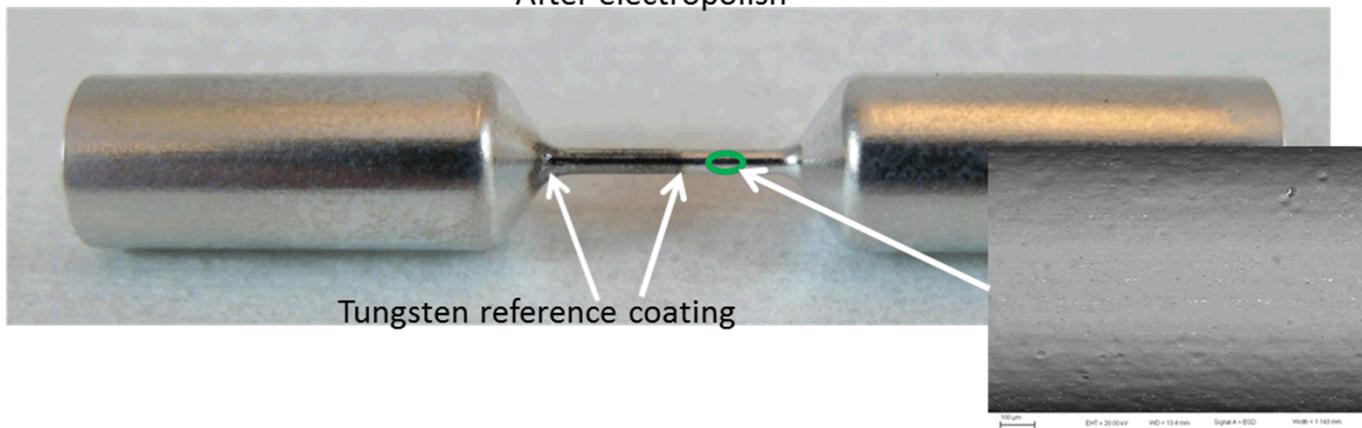
- **Ultra-smooth barbell loads** make ETI studies possible
→ provided Low Technical risk
- Ultra-smooth **mini-liner** **implosions** will evaluate ETI effects at high acceleration
→ results in highest technical risk

target fabrication

Al 6061 Barbells - Before electropolish



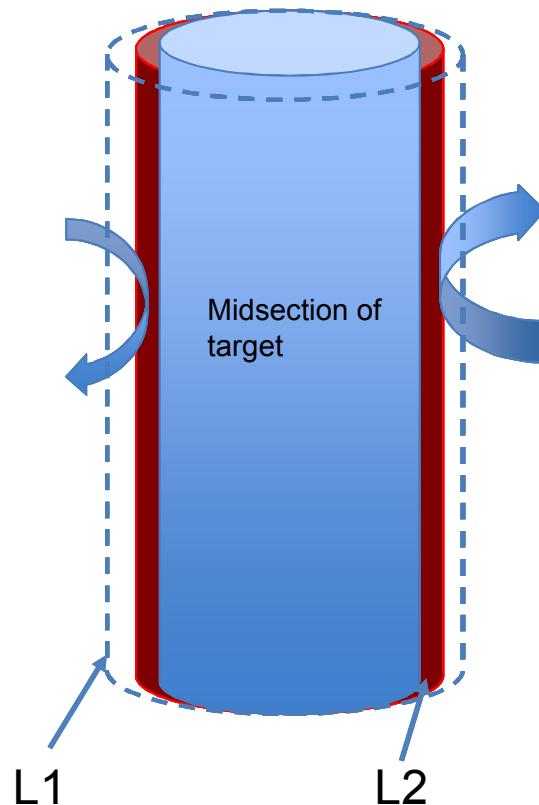
After electropolish



Onion skin approach

Goal is to remove nano-layers of material to minimize high current density electropolishing alone edges and narrow wire

Selective
Aluminum
Barrier
Anodization and
Strip



Nano-polishing of 5N pure Al

5N Aluminum Barrier Anodization and Strip

Chemistry: 3% Ammonium Tartrate

3 mass% tartaric acid

NH₄OH added to pH = 5.5

Chemistry: Chromic Acid Etch

0.4M H₃PO₄ (27.4 ml/L)

0.2M CrO₃ (20g/L)

Process:

T= room temp for 3% ammonium tartrate chemistry

Metal beaker counter electrode

Bubble air through chemistry while anodizing

1) Apply 25-50V for 2 minutes;

2) Rinse;

3) Etch in Chromic acid etch for 10 minutes (**T = 60°C** for etch chemistry)

Repeat process if necessary then use fluoroboric acid

5N Aluminum Electropolishing

Chemistry:

2.5 vol% (fluoroboric acid) HBF₄ (eg. 7.5 ml of 50%HBF₄ per 150 ml of chemistry)

0.1M (ammonium bifluoride) NH₄HF₂

Electropolishing Parameters:

T= room temp

Metal beaker counter electrode

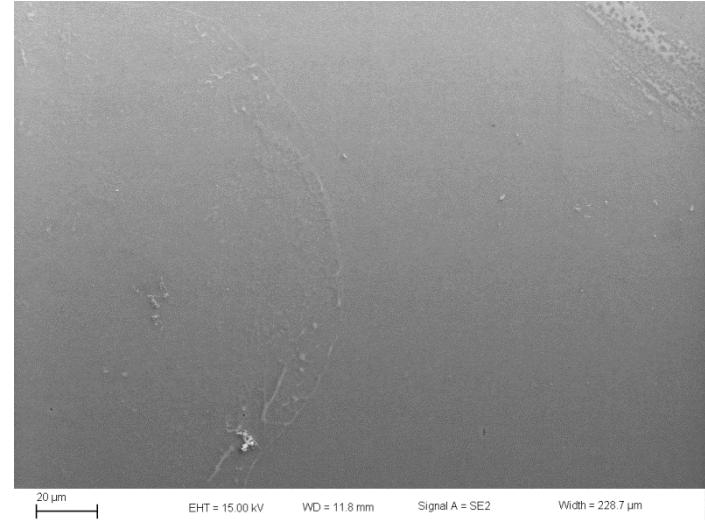
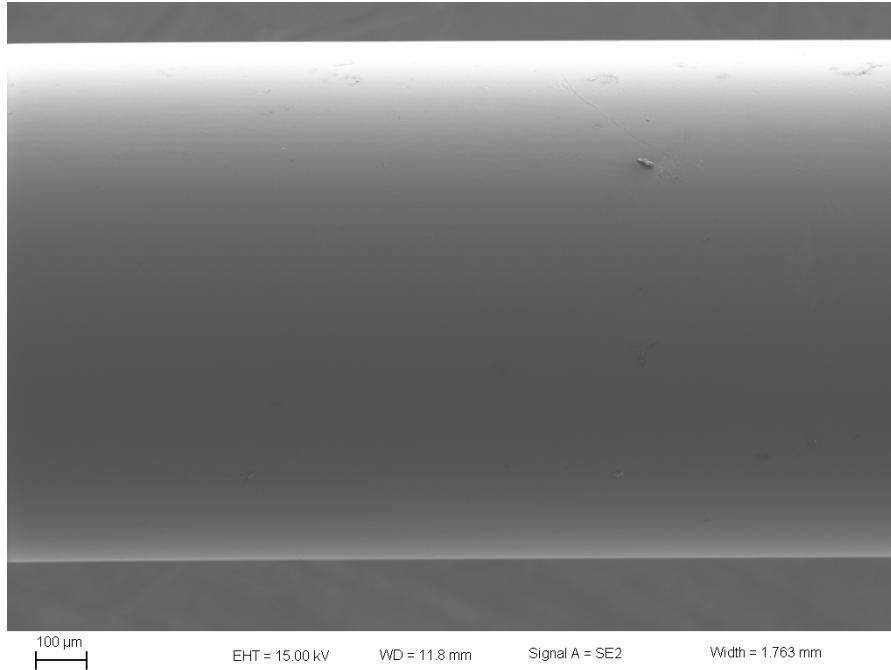
Potentiostatic pulse: 1A for 0.05 seconds

0A for 2 seconds

60 cycles for a total of 3 seconds “on” time

5N's pure Aluminum load

Diamond-turned finish followed by pulse electropolishing



Very few, if any, inclusions are identified and the surface is nearly perfect, in comparison, although several μm -scale defects are still present

Nano-polishing for Al 6061

Al 6061 Aluminum Barrier Anodization and Strip

Chemistry: 3% Ammonium Tartrate

3 mass% tartaric acid

NH₄OH added to pH = 5.5

Chemistry: Chromic Acid Etch

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Metal beaker counter electrode

Bubble air through chemistry while anodizing

1) Apply 25-50V for 2 minutes;

2) Rinse;

3) Etch in Chromic acid etch for 10 minutes (**T = 60°C** for etch chemistry)

Repeat process if necessary then use fluoroboric acid

Al 6061 Pulse Electropolish

Chemistry:

60% by volume H₃PO₄

40% polyethylene glycol (PEG)

Average chain length of 1000

Process:

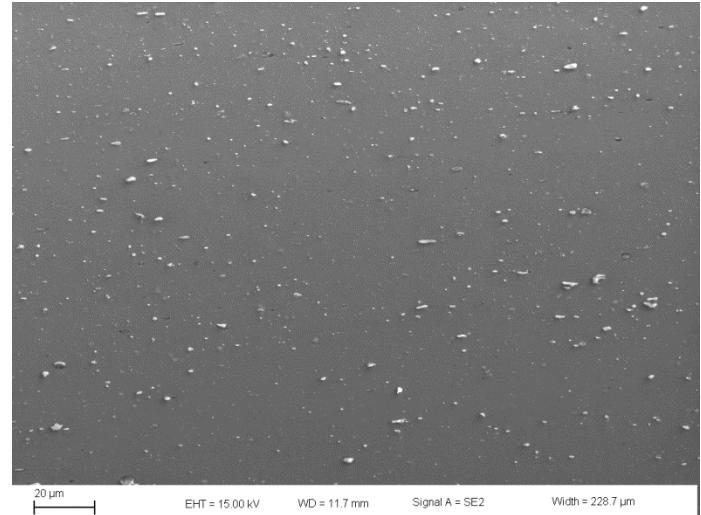
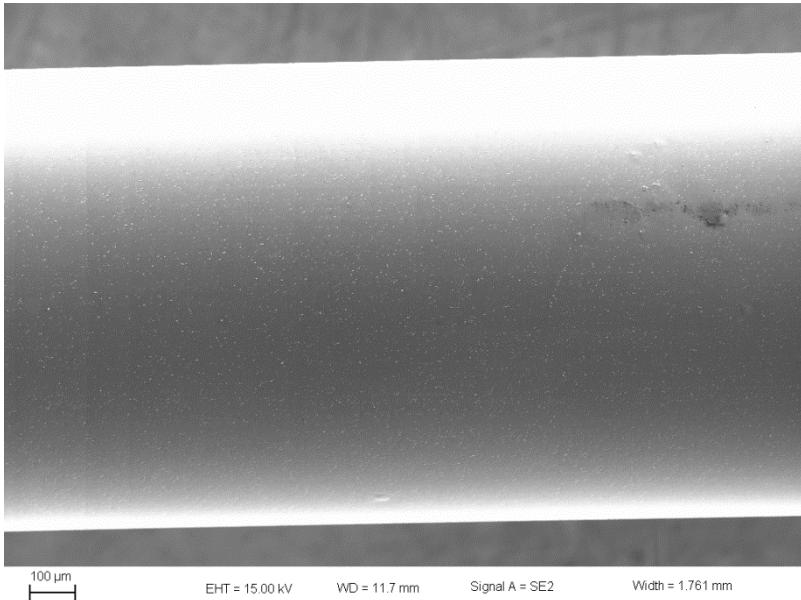
T=70°C and stirring at 1000rpm

A steel beaker is used as the counter electrode

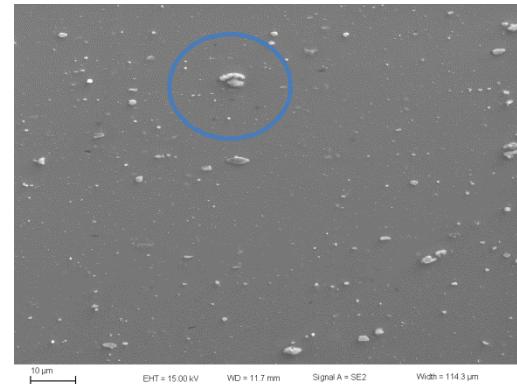
Electropolish using potentiostatic pulsing: 8V for 0.1sec /
Open circuit potential for 2 sec
20 cycles

6061-T6 Aluminum load

Diamond-turned finish followed by pulse electropolishing



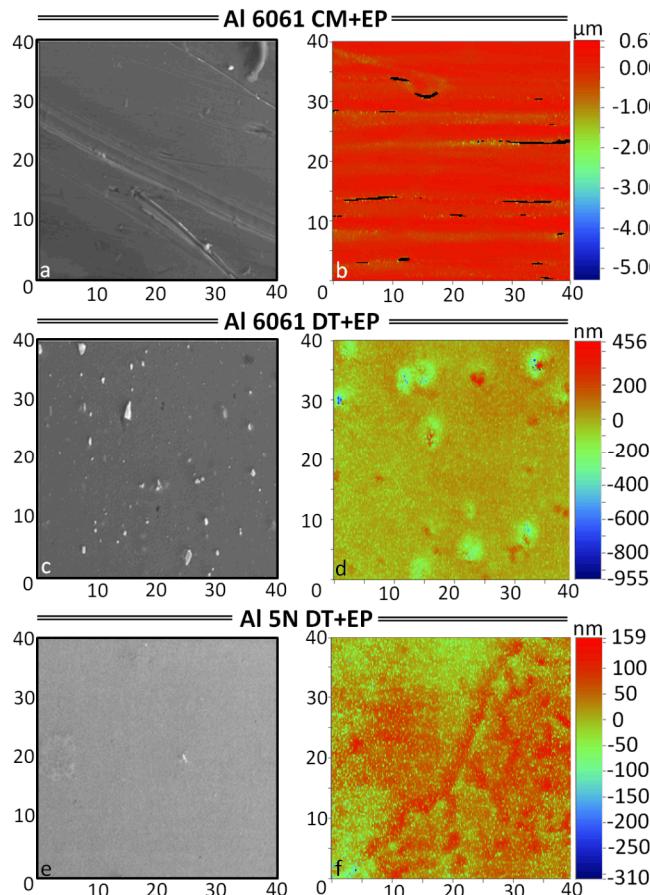
Inclusions are predominantly composed of silicon and magnesium.



Various techniques to nano-finishes

SEM (secondary electron) characterization and (a,c,e)

The “roughness average” (R_a , the arithmetic average of absolute values of the vertical offset from the mean surface height)



White-light interferograms in (b), (d), and (f), are 170 nm, 42 nm, and 29 nm, respectively.

Axes are in μm .

The evolution of surface emissions from Joule-heated Al rods of varying alloy and fabrication technique are shown

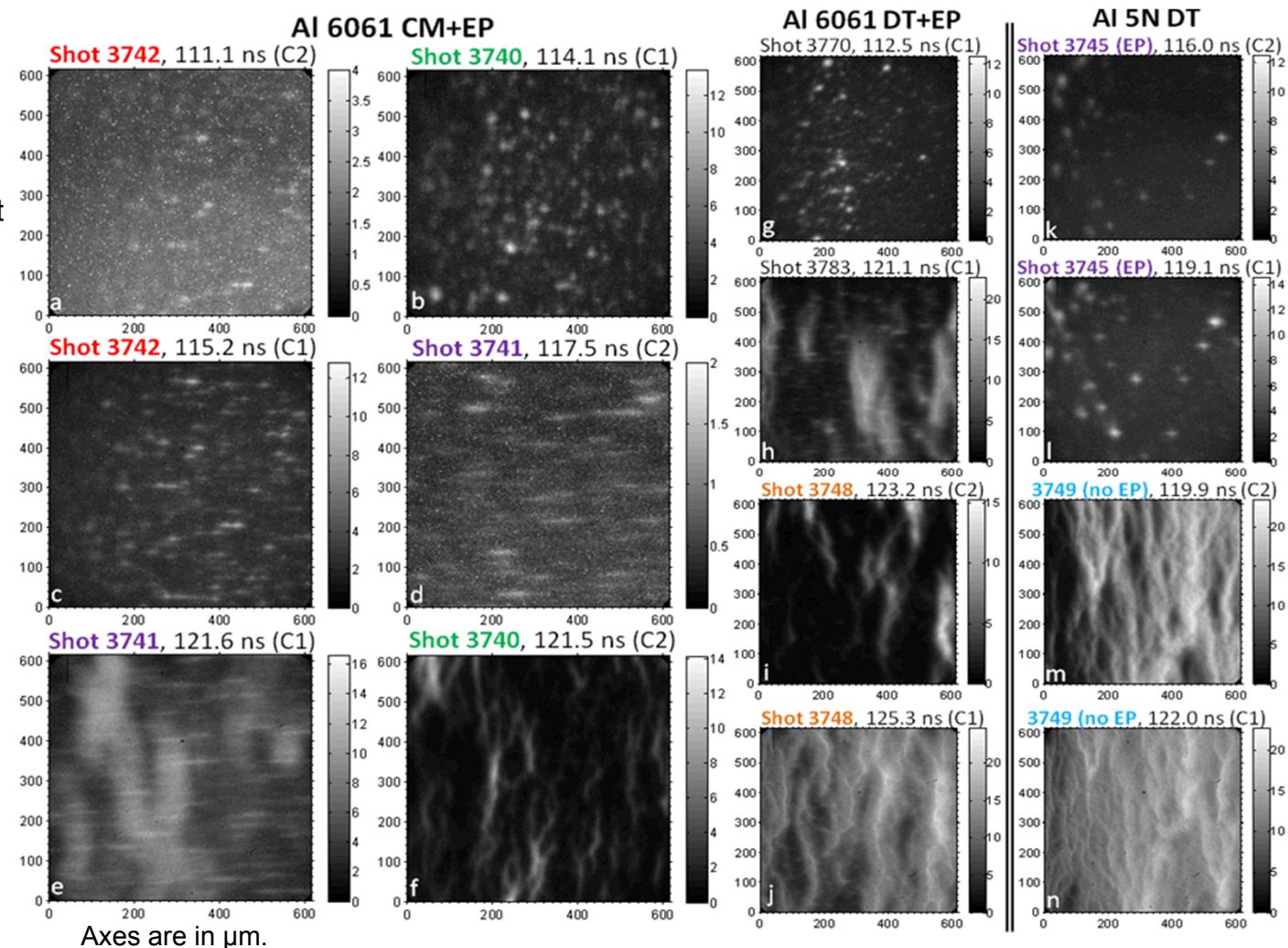
Early heating phase
@~115ns

Elliptical spots and distinct strata (c,d, and e)

Strata potentially results in highly effective seed perturbation for the MRT instability

Filament emission (f,I,j, m, and n)

Cm=conventionally machined;
DT=diamond turned
EP= electropolish
C1, C2= cameras 1 and 2



Note the delay (119ns) and low density of spots and strata for Al 5N DT (k and l)

Summary and conclusion

When spots elongate in the direction perpendicular to the current flow; this occurs because current bends azimuthally around the defect, leading to enhanced current density at the edges, which results in overheating and increased local resistivity.

Experiments capture this phenomena which are clearly 3D in nature, evolve rapidly over few-ns timescales, and may originate from μm -scale features on or within the metal;

Preliminary results inform how global structures (e.g. strata or filaments) can evolve from isolated surface defects.

Future experiments will include engineered defects in 5N targets with known size and composition

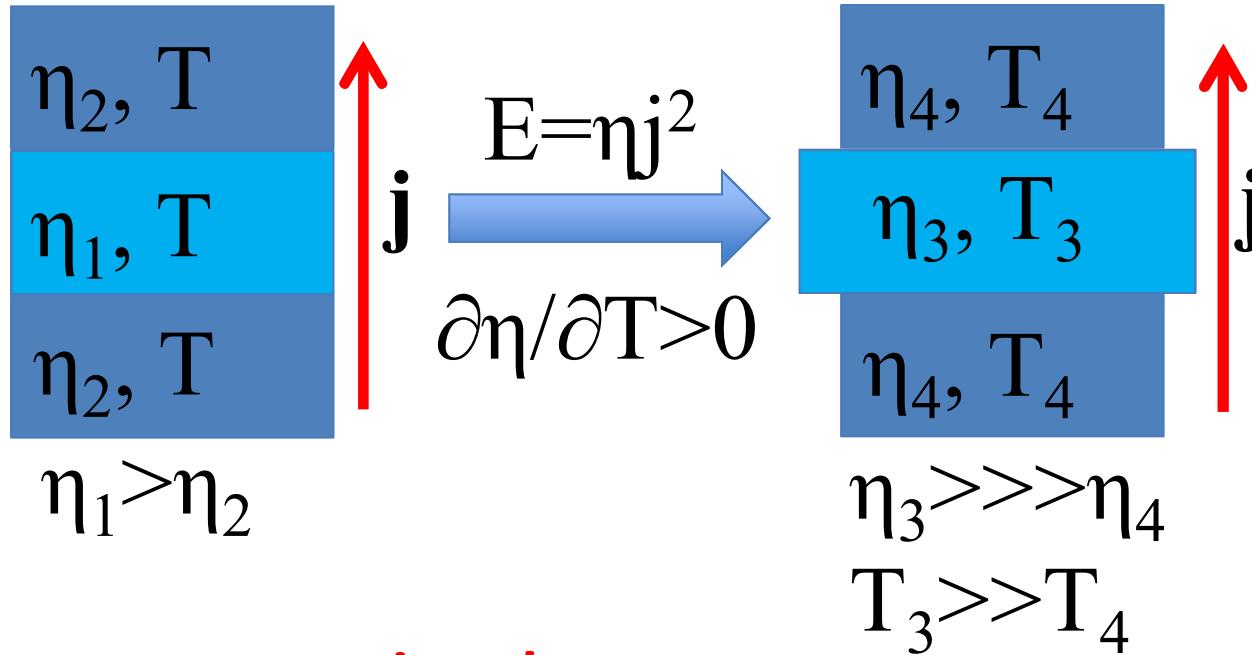
Acknowledgments

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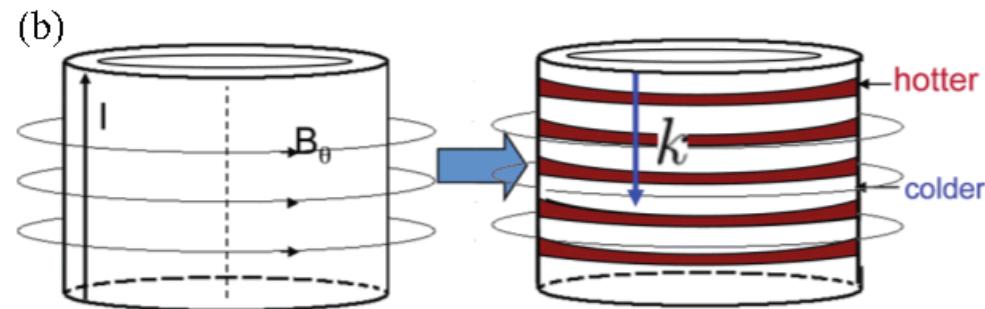
This work was funded in part by Sandia's Laboratory Directed Research and Development Program (Project No. 178661). Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

BACKUP SLIDES

Electrothermal instabilities occur when material conductivity is dependent on temperature



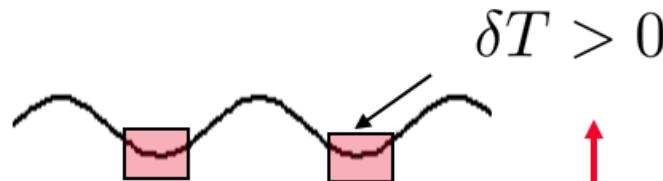
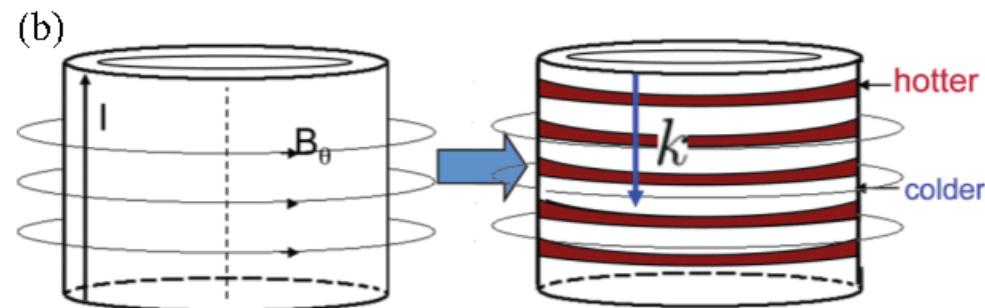
ETI can generate striated density perturbation on the liner surface very early in the experiment
 → provides seed for MRT



Electrothermal instabilities occur when material conductivity is dependent on temperature

Striations

$$\frac{d\eta(T)}{dT} > 0$$



Temperature perturbations give rise to pressure variations which eventually redistribute mass

Consider a small temperature perturbation due to localized variations in ohmic heating

- surface contaminants (variations in η)
- surface roughness ($B_0 \sim I/r$, in cylinders)

Then, η increases which consequently further enhances the localized ohmic heating (ηj^2),

which leads to increased δT