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Electrothermal Instability Evolution on Z-Pinch Rods and Imploding Liners Pulsed with Intense Current

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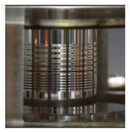
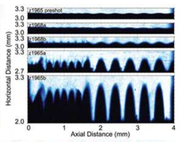
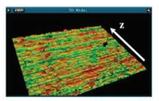
Z experiments have focused on developing predictive capability of instability growth of imploding liners

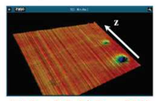




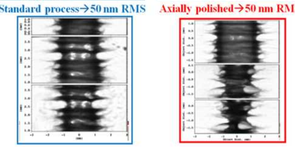
D.B. Sinars *et al.*, Phys. Rev. Lett. 105, 185001 (2010)
D.B. Sinars, Invited Presentation, 2010 APS-DPP

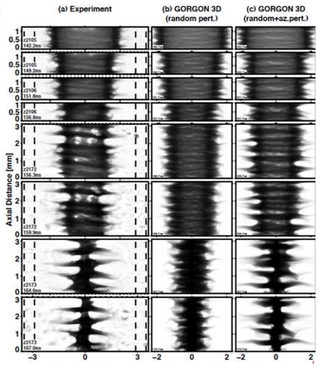


Standard process→50 nm RMS



Axially polished→50 nm RMS

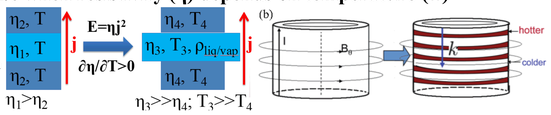




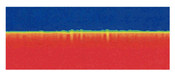
R.D. McBride *et al.*, PRL 109, 135004 (2012)
R.D. McBride, Invited Presentation, 2012 APS-DPP

Electrothermal instabilities are driven by Joule heating and arise when resistivity (η) depends on temperature (T)

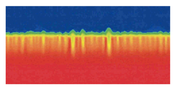
Condensed Metal
- $\partial\eta/\partial T>0$
- ↑ η_0 ↔ ↑ηj^2 ↔↑T
- Drives nonuniform phase change and expansion



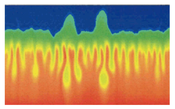
2D simulations show ETIs develop after melt and seed later MRT growth



Locations of higher Joule heating vaporize & expand first→Density perturbations form

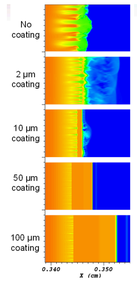


The Magneto-Raleigh Taylor (MRT) instability grows from the ETI seed, and begins to dominate



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

But, ETI-driven density perturbations are mitigated with dielectric surface coatings!

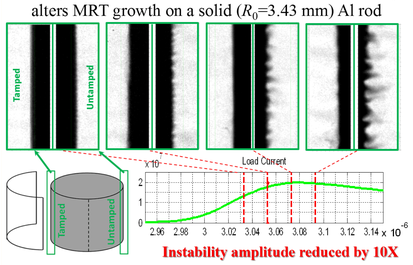


Thick (>10 μm) insulating coatings mitigate effects of ETI and reduce seed for MRT growth

No ETI strata in the dielectric

Mass redistribution from ETI is significantly tamped by the coating
- Reduces seed for MRT growth
- Reduces integral instability growth

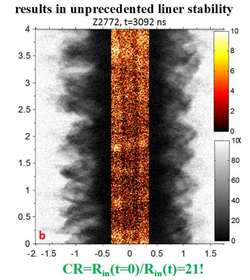
Adding a 70-micron-thick dielectric tamper dramatically alters MRT growth on a solid (R_0=3.43 mm) Al rod



Instability amplitude reduced by 10X

K.J. Peterson, *et al.*, PRL **112**, 135002 (2014)

Combining axial premagnetization with a dielectric tamper for ETI mitigation results in unprecedented liner stability



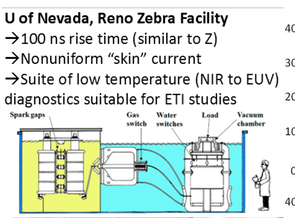
CR=R_{in}(t=0)/R_{in}(t)=21!

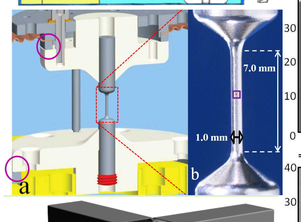
T.J. Awe, *et al.*, PRL **116**, 065001 (2016)

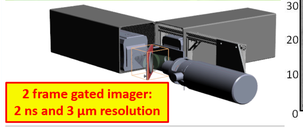
The early nonuniform Joule heating of Z liners is not diagnosed. Rather, ETI development is inferred by evaluating MRT late in the experiment. ETI is NOT directly observed!

Nonuniform Joule heating is observed with unprecedented diagnostic resolution

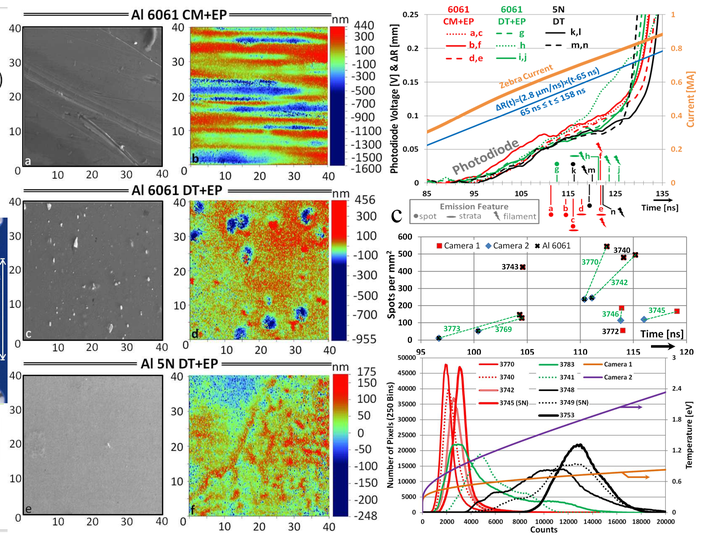
U of Nevada, Reno Zebra Facility
→100 ns rise time (similar to Z)
→Nonuniform "skin" current
→Suite of low temperature (NIR to EUV) diagnostics suitable for ETI studies



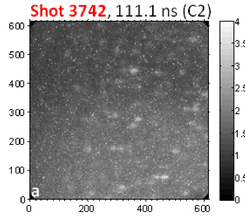




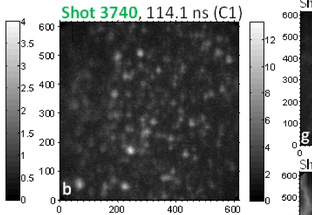
2 frame gated imager: 2 ns and 3 μm resolution



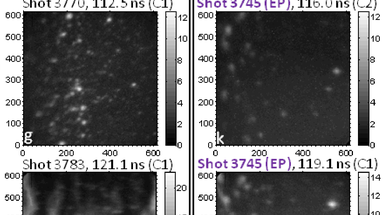
Al 6061 CM+EP



Al 6061 DT+EP



Al 5N DT



T.J. Awe, *et al.*, IEEE Trans. Plasma Sci. **45**, 584 (2017)

For Al 6061 alloy, newly observed early phenomena include overheated azimuthally stretched elliptical spots (20-40 μm wide by 10 μm tall) and distinct strata (40-100 μm wide by 10 μm tall). Data give credence to the hypothesis that early nonuniform Joule heating, including ETI, may provide the dominant seed for MRT

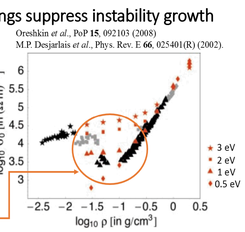
Dielectric surface coatings tamp expansion and mitigate surface plasma formation, providing a unique platform for studying ETI strata formation and evolution

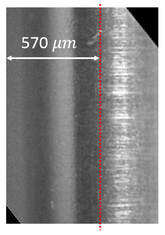
Thin-wire ETI Theory → Dielectric coatings suppress instability growth

$$\gamma = \frac{j^2\frac{\partial\eta}{\partial T} + \frac{\rho}{T^*}\left(c_v\frac{\partial T}{\partial t} - j^2\frac{\partial\eta}{\partial\rho}\right) - k_z^2\kappa}{c_v\rho + \frac{p}{T^*}}$$

Oreshkin *et al.*, PoP **15**, 092103 (2008)
M.P. Desjarlais *et al.*, Phys. Rev. E **66**, 025401(R) (2002).

1. Dielectric inhibits motion of $\delta\rho$, suppressing the ETI growth rate dependence on $\partial\eta/\partial\rho$.
2. Dielectric keeps material out of the bi-phase regime where $\partial\eta/\partial T$ is large.



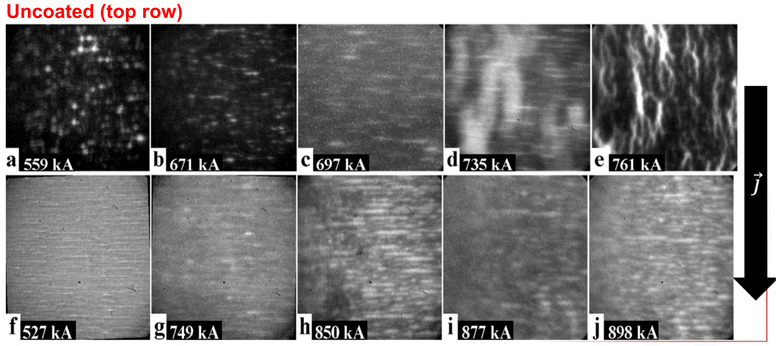


70 ± 5 μm of dielectric was chemical vapor deposited onto five rods

70 μm transmits 85% visible light

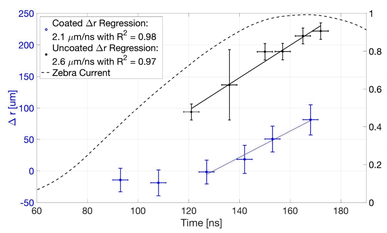
Machining structure visible through Parylene in optical microscope pictures

Uncoated (top row)

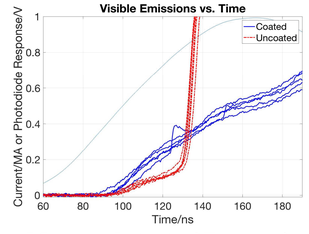


Dielectric coated (bottom row)

Shadowgraphy indicates appreciable tamping of Al expansion



Coated loads emit more strongly early in time due to reduced pdV cooling

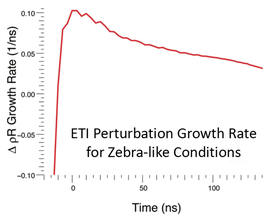


Both Theory (thin wire) and MHD simulation suggest δT grows in time

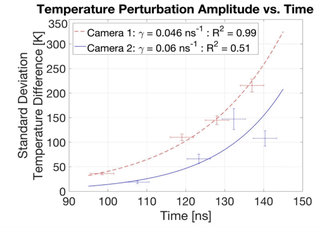
Using Zebra-relevant conditions, and analytic theory we estimate

Thin-Wire Analytic
→ $\gamma \sim 0.037\ ns^{-1}$

Thick-Rod MHD
→ $\gamma \sim 0.1\ ns^{-1}$



Measured strata δT grows in time and is best fit with an exponential



The first direct observation of stratified ETI on the surface of thick metal has been made. Dielectric coatings inertially tamp the metal and suppress surface plasma formation, enabling prolonged observation of strata. Radiometry indicates exponential growth of temperature perturbations.