Liquid electrodes for harsh environments and kinetic theory for plasma discharge control

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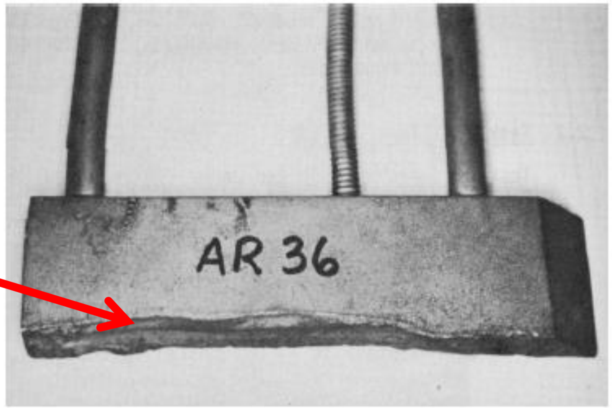
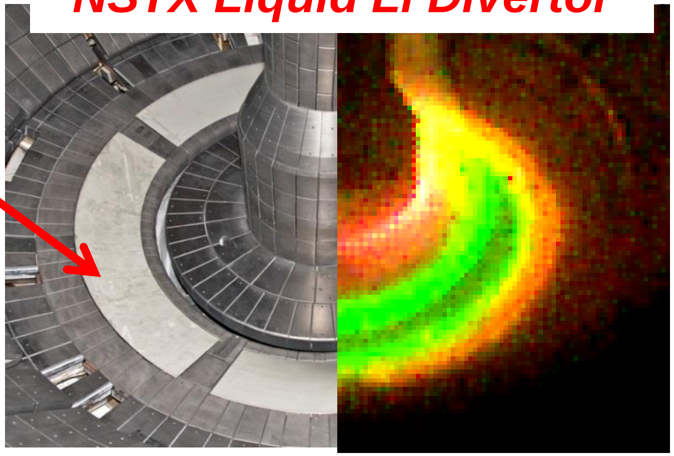
Fusion technologies and kinetic theory can be leveraged for MHD Power Generation

- Electrode lifetime can be extended by using a replenishable, self-healing material (i.e. liquid)
- Porous structures already demonstrated to resist MHD forces
- PPPL could examine key questions for technology
  - Near-surface PMI processes
  - Transport of eroded material
  - Selective erosion and composition control
  - Impact of liquid PMI on overall performance



Geo. A. Richards, Princeton-CEFRC Summer School, 2012

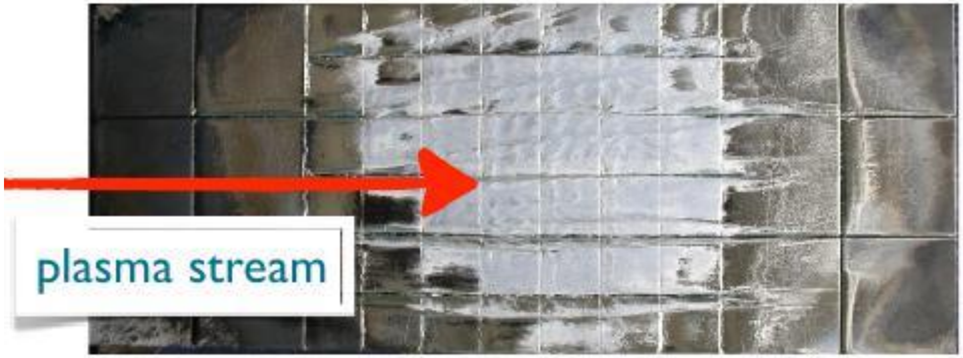
NSTX Liquid Li Divertor



Fusion needs a game-changing technology to make economical electricity

- Fusion edge plasmas are extreme environments
- Erosion rates expected to limit component lifetime and reactor uptime
- PPPL has led the development of liquid plasma-facing components to meet the challenges

Coenen, et al., JNM 2013

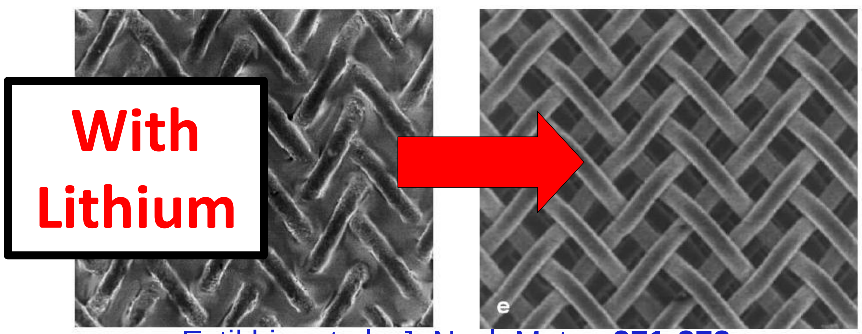


Klimov, et al., JNM **390-391** (2009) 721.

Liquid plasma-facing components are a revolutionary approach

- No permanent damage to the electrode surface, just replace it with fluid flow!
- Increased power loading by elimination of thermo-mechanical stresses
- Porous substrates demonstrated to restrain liquid against MHD forces

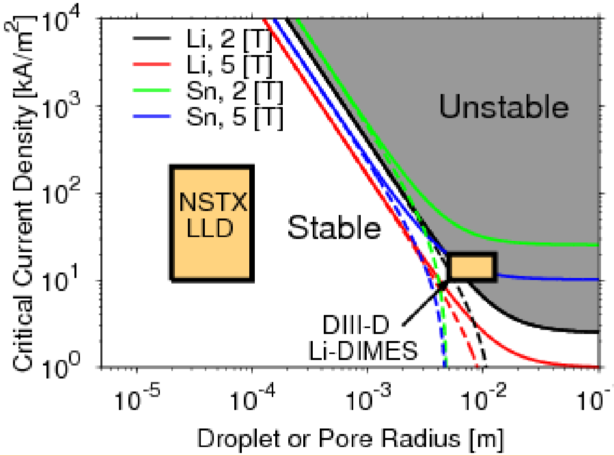
Pre-exposure ***Post-exposure***



Evtikhin, et al., J. Nucl. Mater. **271-272** (1999) 396.

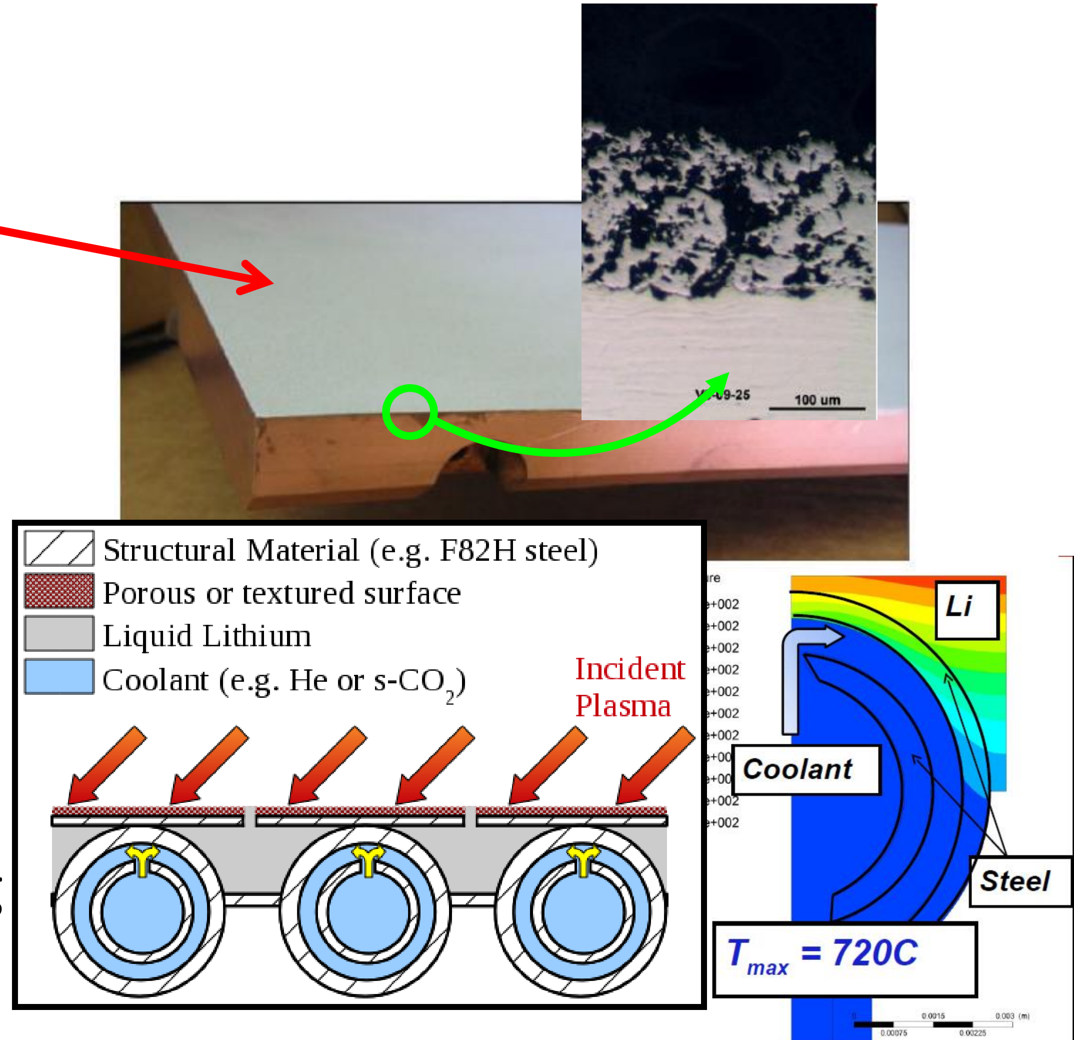
$$j_{cr} = \frac{1}{B}\left(\frac{4\pi^2}{\lambda^2}\Sigma + \rho g\right)$$

For the fastest growing modes



PPPL is leading the world in deploying liquid plasma-facing components

- Liquid Lithium Divertor demonstrated stable operation against MHD ejection forces
- High-temperature plasma tests developing understanding of material transport
- Reactor-relevant PFCs being design for next-step devices



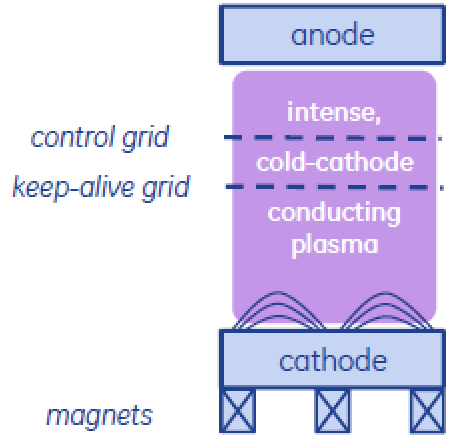
Summary and Outlook

- Liquid electrodes may be a game-changing technology for both fusion and MHD power generation
- State-of-the-art kinetic simulations can speed the development cycle of new technologies and provide new directions for research
- PPPL core experience in plasma physics can be leveraged with both experimental and theoretical endeavors

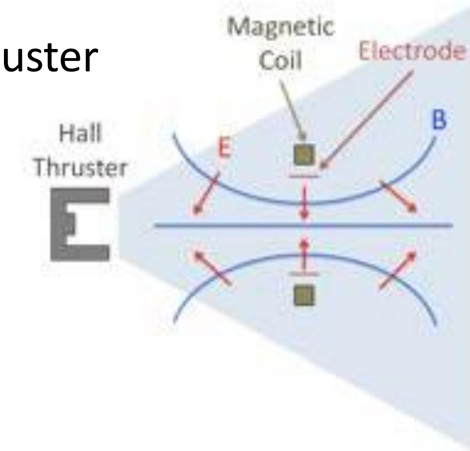
Plasma kinetic theory and modeling has enabled unprecedented control of discharge plasmas

- Particle-in-Cell (PIC) simulation is a key tool
- Simulations cross broad spectrum
  - Simple 1D electrostatic to full 3D electromagnetic
  - From low-temperature processing plasmas to fusion applications
- PIC simulations can provide detailed information on impact of wall material, biasing and geometry

High-power switch

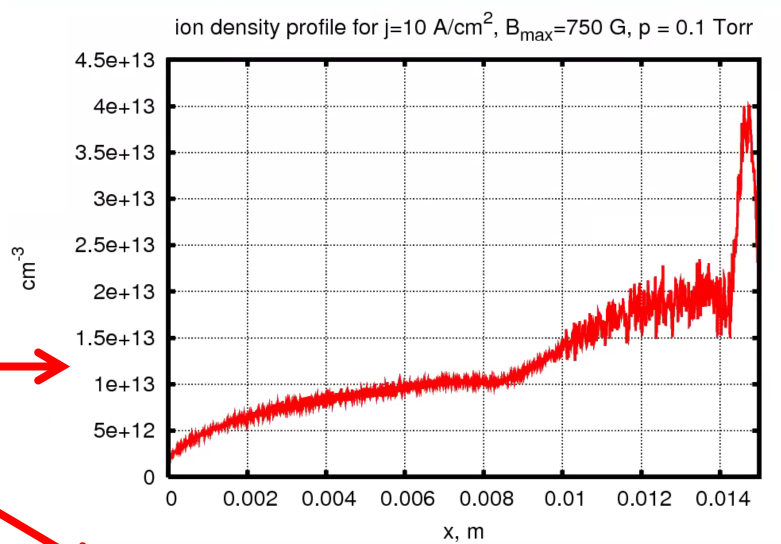


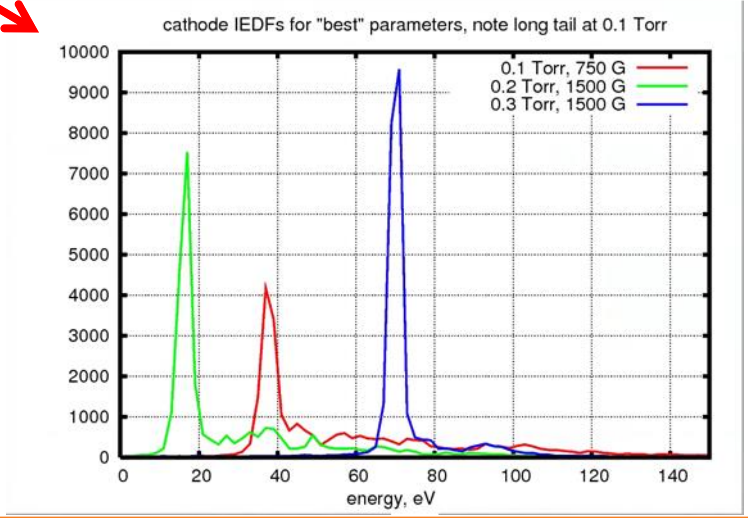
Hall thruster



Kinetic modeling already applied successfully to numerous applications

- Magnetic filtering in high-power
  - Control of hot-electron population
  - Allows tailored discharges with control of transport, instabilities and erosion
- Electron beam-seeded discharges examined for large-scale process plasmas to understand experimental results
- Hall thruster performance dependence on wall material and geometry





Kinetic plasma modeling applied to MHD power generation could optimize seed-free operation

- Electron beams and dielectric barrier discharges already demonstrated in MHD systems (Miles, 2006)
- Elimination of seed material could also improve electrode lifetime
- Validated models can speed technology development cycle

EEDF control with electrode geometry and biasing