Tungsten Velvet Armor
for HAPL Fusion Energy Systems

Timothy R. Knowles
Energy Science Laboratories, Inc. (San Diego, CA)

August 8, 2006

W-Velvet Armor

Architecture

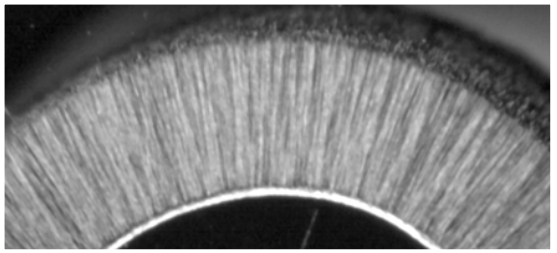
- Straight cylindrical fibers, 20μm D x 500μm L
- Oriented nearly perpendicular to wall ($\Delta\theta$ <5°)
- Packing fraction > 20-40%
- >10x surface area accessible line of sight
- Sharp tips

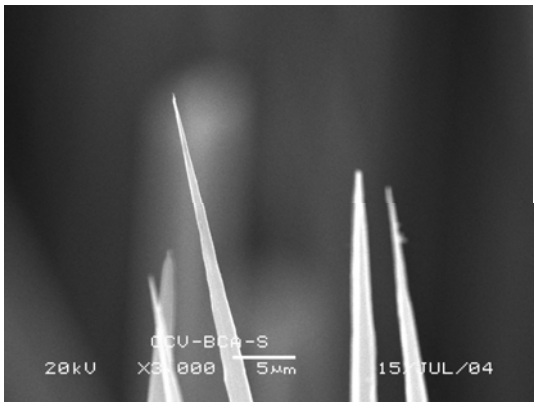
Benefits

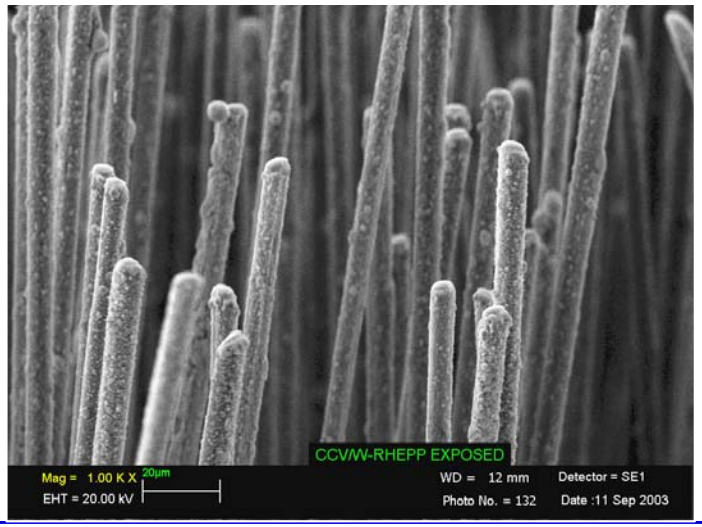
- Higher damage threshold over most area
- Lower local flux, lower surface T
- Less sputtering at high incidence angles
- Redep is deposited locally, recycled

Tungsten fibers?

- CVD W onto C Velvet
- Options: Etch away C(?); Anneal to WC (?)







Performance

Thermal Performance

- Conduction gradient <25 K for 1 MW/m^2 average power
- Surface T response 10x lower than flat surface over most of area
- Tips run cooler than flat W because the radiating area is larger

Gas Retention behavior unexplored

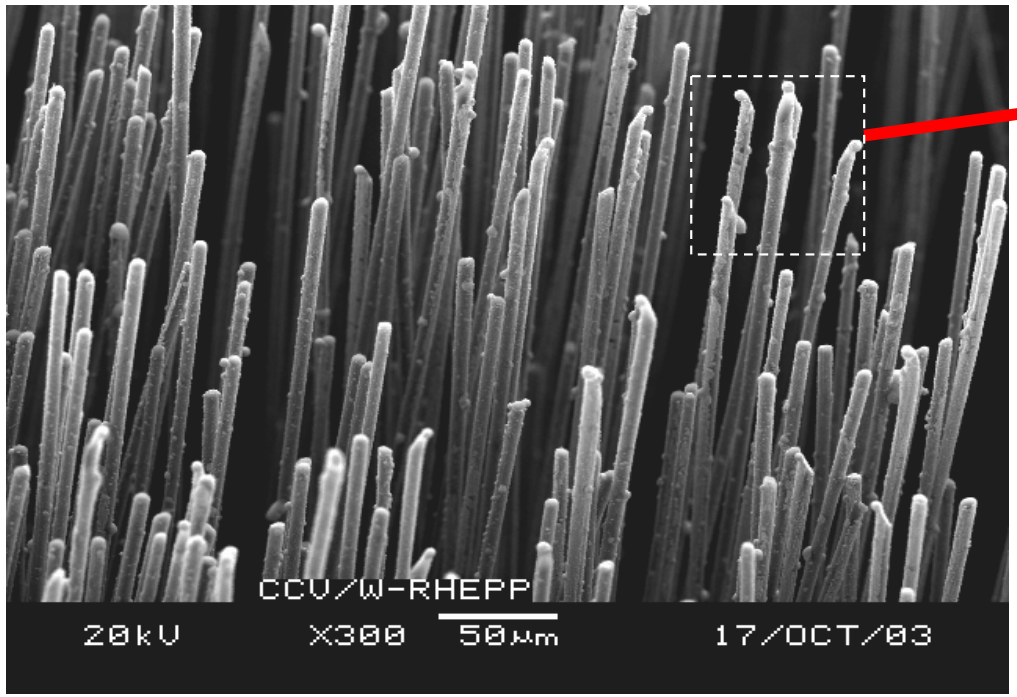
- Grazing incidence may implant less deeply
- Short diffusion length

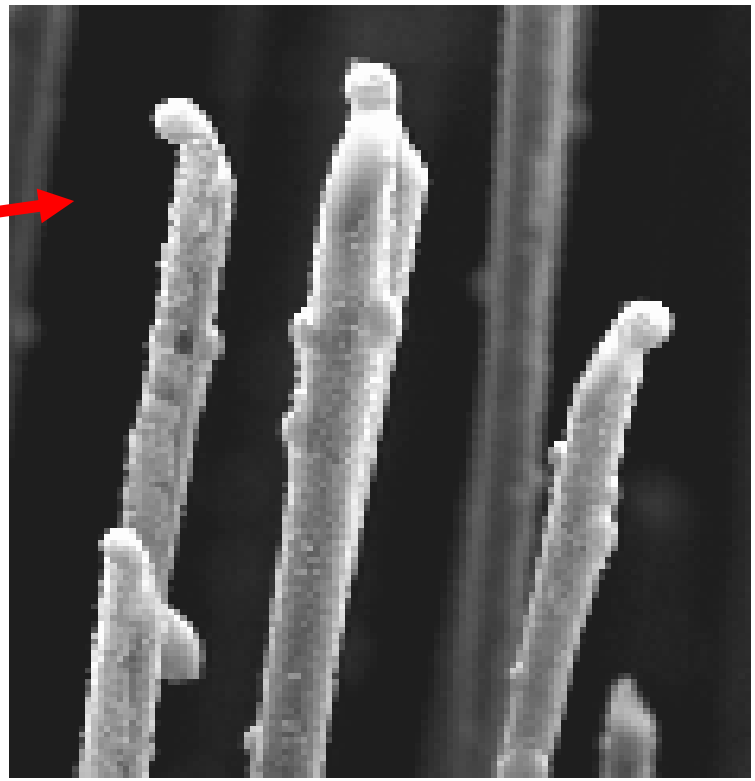
Various exposures to pulsed power have been performed

SNL	RHEPP (ion), BEAMLET (photon), Z (Xray)
WSMR	High energy laser (IR)
JPL, CSU	High fluence sputter (ion, high fluence life test)

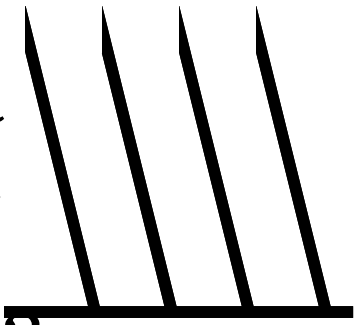
After RHEPP: Beaded Tips

The longest fibers are found to have sharp tips with one W bead
Bead appears to melt… but adheres to tip.
Perhaps phase-change thermal inertia protecting tips?





Simple Model: Louver Armor



Consider louver armor with 5x area

- 10 μm thick *x* 500 μm long *x* 100 μm spacing

Louvers are 5x cooler over most area

- Tips are hottest, but less hot than a flat surface because of radiation cooling

Issues

- High cost
- Thermal-mechanical behavior?
- Deformation or warp fatal here?

WC Velvet in RHEPP

Heat treated W on C

- 11μm WC sheath diam
- 5 μm carbon fiber core

High RHEPP exposure