Plasma Facing Component Development at PPI

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Plasma Processes, Inc.

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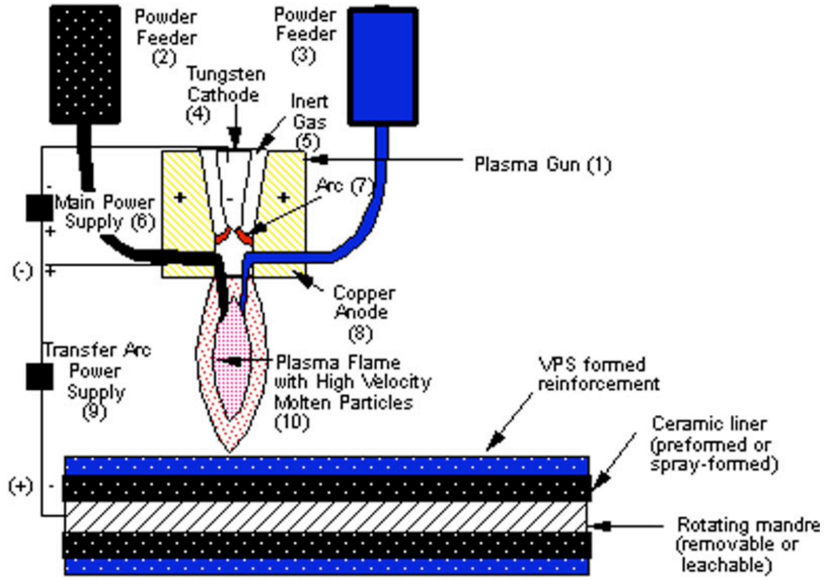
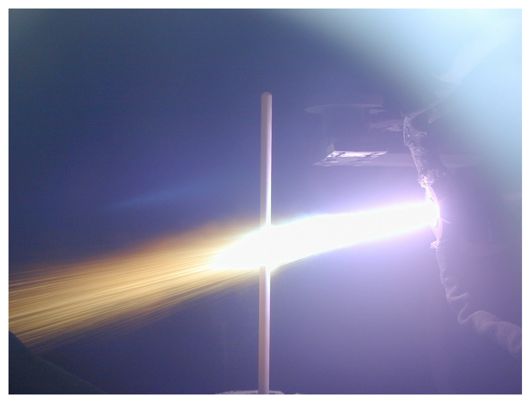
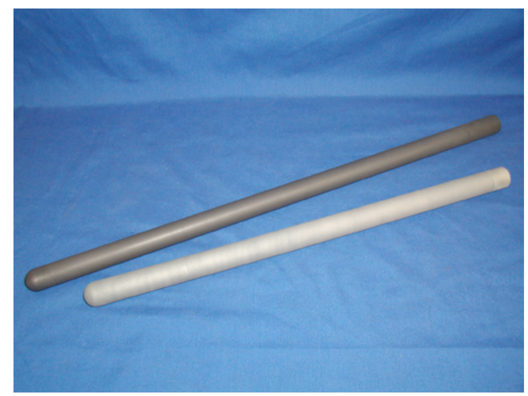
Background

- Plasma Processes, Inc. is a small business that specializes in the development and fabrication of coatings and near-net-shape spray formed structures using Vacuum Plasma Spray (VPS) forming techniques.







Advantages of VPS Forming Techniques

- Processing of oxygen sensitive materials
- Ability to use reactive gases
  - H_2 for O_2 reduction
  - N_2 for nitriding
- High temperature plasma enable processing of high melting temperature materials
  - Refractory metals (e.g., W, Re, Mo, Ta, Nb)
  - Ceramics (Al_2O_3, Y_2O_3, HfN)
  - Carbides (e.g., TaC, HfC)
- CNC control enables contour following and uniform, repeatable deposition thicknesses
- High deposition rates (e.g. >10kg/hour)
- Deposition of alloys and dispersion strengthened materials
- Net shape (near) spray formed components using removable mandrels
- Post-spray heat treatments can result spray formed materials with density >99% and properties equivalent to or exceeding wrought materials
- Ability to tailor the structure of the deposits by varying the spray parameters
  - Porous structures
  - Functional gradient layers for joining materials with dissimilar CTEs
  - Multi-layered structures

PFC Development

- Armor
  - VPS W and Be
  - W and Be brush
- Spray Formed Refractory Metal Heat Sinks
  - Liquid Metal Cooled
  - He Cooled
- Engineered Materials
  - Nanograined W
  - Nanoporous W armor for laser IFE

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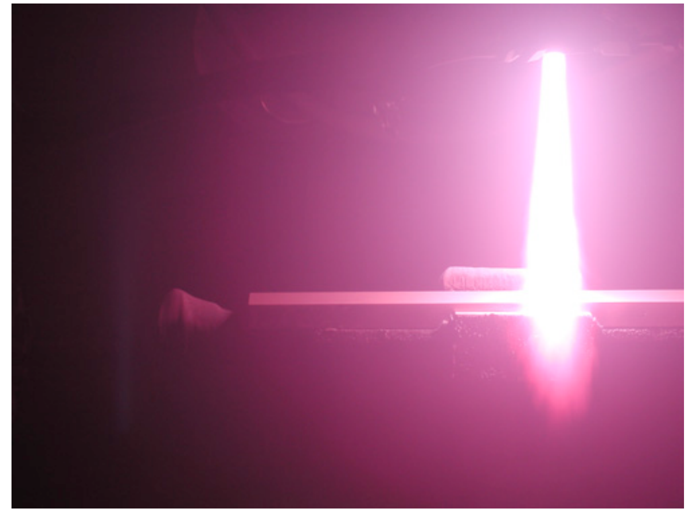
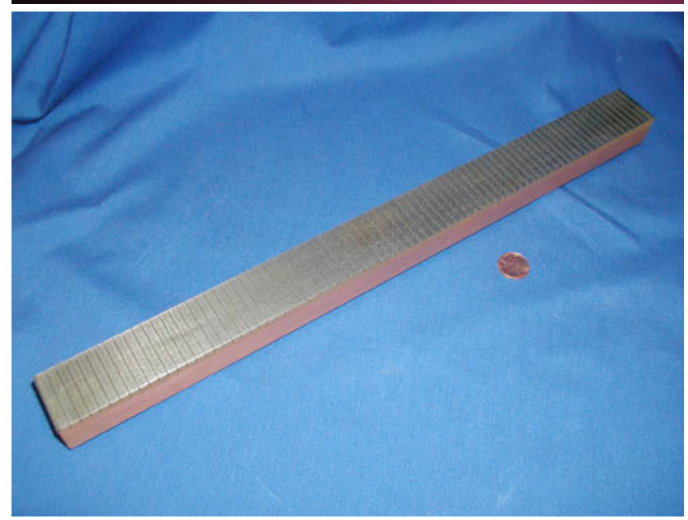
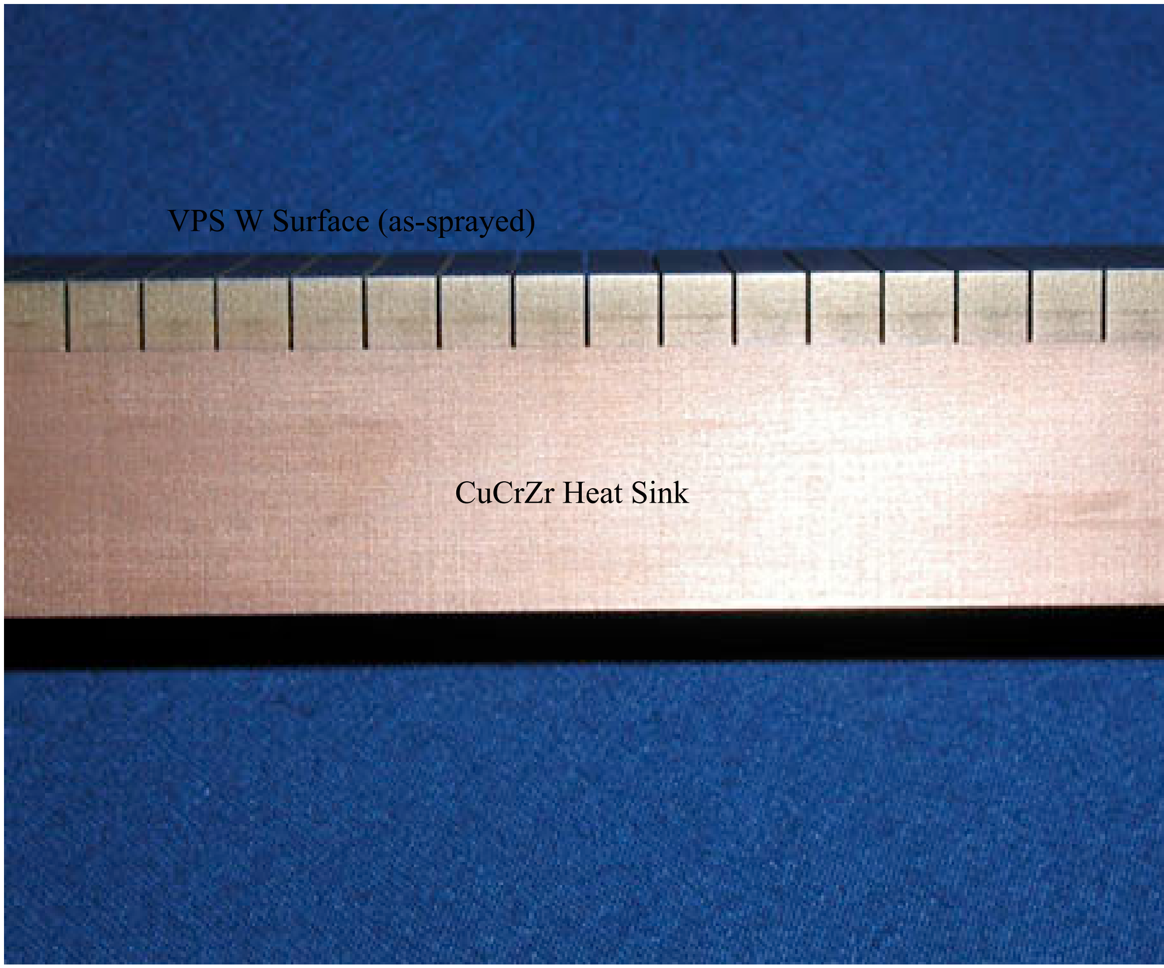
VPS Armor on Cu Alloy Heat Sinks

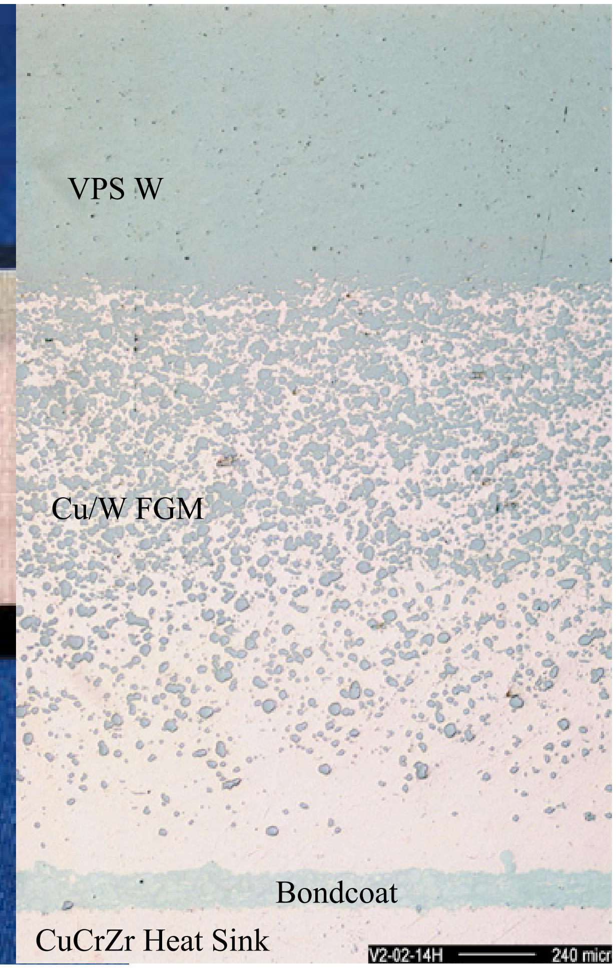
- Ar/H_2 Plasma
- Rectilinear pattern
- CuCrZr heat sink
  - 400mm length x 40mm width
- Cu/W functional gradient to reduce stress due to CTE mismatch
  - W: 4.4×10^{-6}/K
  - Cu: 16.8×10^{-6}/K
- 2mm gradient enabled the VPS deposition of 5mm thick W deposits
- After deposition, width trimmed to 32mm and armor castellated





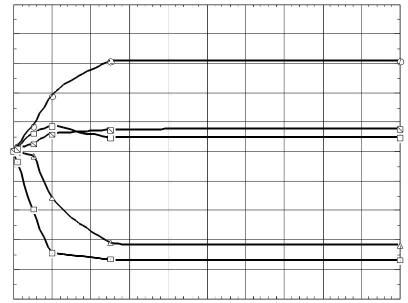
VPS W Armor on a CuCrZr Heat Sink

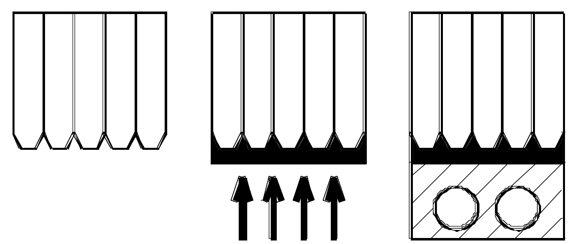




Brush Armor

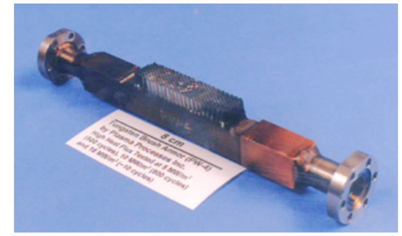
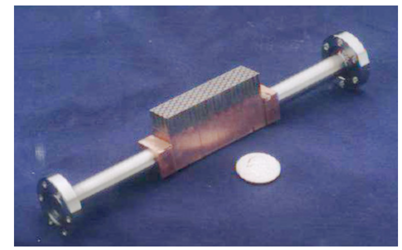
- SNL showed by reducing the tile width the stress at the tile/heat sink interface can be reduced
- Using preformed W and Be rods, a VPS backing material is deposited on the tips of the rods
  - Fine grain microstructure
  - Ability to apply bondcoats or diffusion barriers
  - Minimal penetration of backing material down the rod length
- Backing material is then joined to CuCrZr heat sink using HIP diffusion bonding or deep penetration electron beam welding

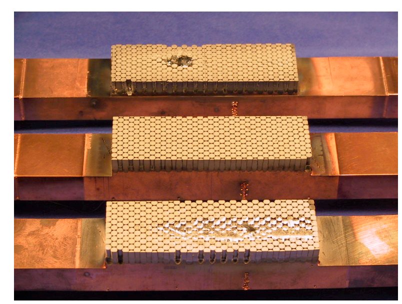




HHF Testing of Brush Armored Mockups

ID Number	Heat Sink (Channel)	Backing Material	Bond Coat	Rod/Tip Configuration	Dam	Armor Height, Width and Length (mm)*	Armor to Heat Sink Bonding
PW-4	Cu alloy (Single)	Cu (1mm)	Ni	W (1.6 mm dia.) 45° pointed	Inconel	10 x 16 x 70	HIP diffusion
PW-10	CuCrZr (Single)	Cu (3mm)	Ni	W (3.2 mm dia.) 45° truncated	Inconel	10 x 16 x 65	E-beam
PB-9	Al 6061 (Single)	Al (3mm)	None	Be (2 x 2mm square) 45° pointed	None	5 x 17 x 65	E-beam
PW-8	CuCrZr (Dual)	Cu (1mm)	Ni	W (3.2 mm dia.) 45° truncated	Inconel	8 x 32 x 102	HIP diffusion
PW-14	CuCrZr (Dual)	Cu (2mm)	Ni	W (3.2 mm dia.) 45° truncated	Inconel	8 x 32 x 102	E-beam
PW-14b	CuCrZr (Dual)	Cu (2mm)	Ni	W (3.2 mm dia.) 45° truncated	Inconel	8 x 32 x 102	E-beam



- W brush armored, dual channeled mockups have survived >20MW/m^2 for 500 cycles and thermal response heat fluxes >25MW/m^2
- Be brush armored mockups have survived HHF testing at 5MW/m^2 for 353 cycles

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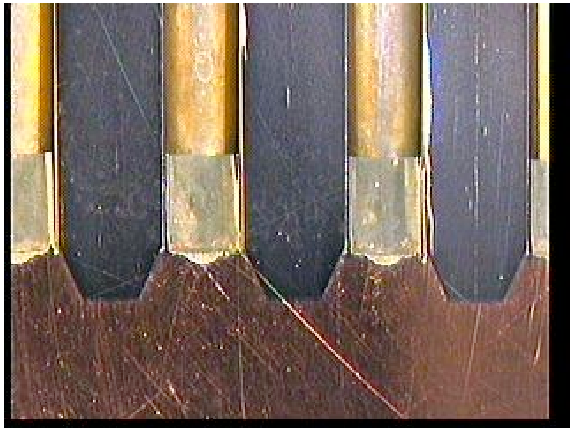
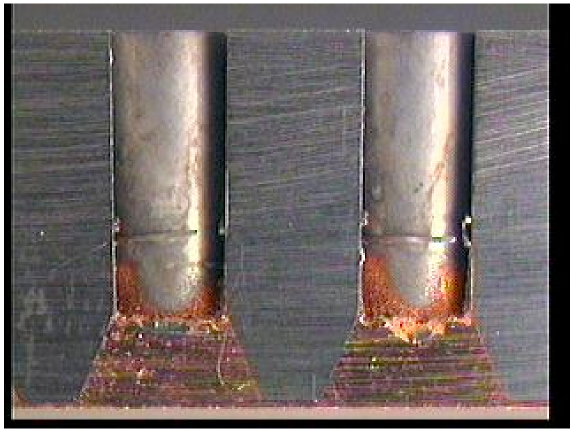
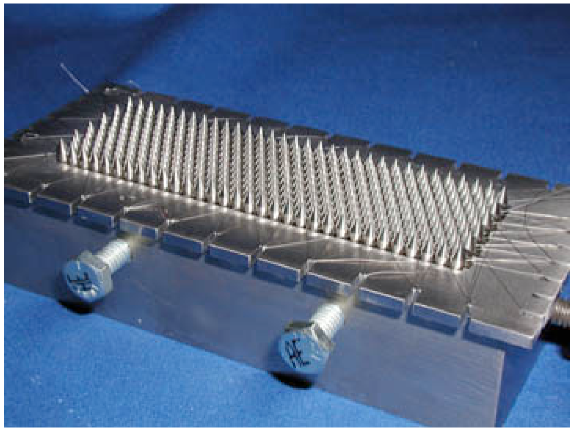
2^{nd} Generation of W Brush Armored, Dual Channeled Mockups

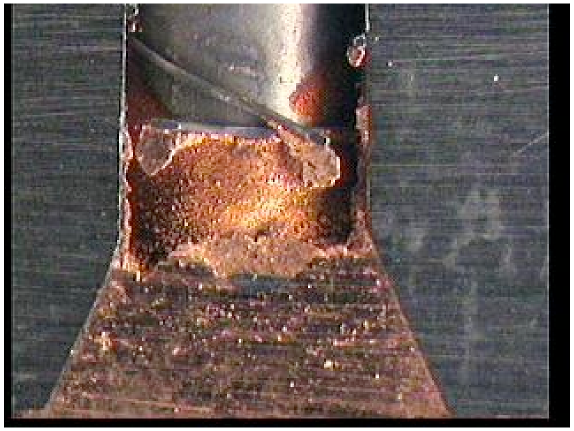
ID Number	Heat Sink (Channel)	Backing Material	Bond Coat	Tip Configuration	Dam	Armor Height, Width and Length (mm)	Armor to Heat Sink Bonding
V2-02-15B	CuCrZr (Dual)	Cu (1mm)	Ni	W (3.2 mm dia.) 45° truncated	W wire (100_m)	5 x 32 x 95	HIP diffusion
V2-02-15F	CuCrZr (Dual)	Cu (1mm)	Ni	W (3.2 mm dia.) 45° pointed	W wire (100_m)	5 x 32 x 95	HIP diffusion
V2-02-15K	CuCrZr (Dual)	Cu (1mm)	Ni	W (3.2 mm dia.) 45° truncated	None	5 x 32 x 95	HIP diffusion
V2-02-15N	CuCrZr (Dual)	Cu (1mm)	None	W (3.2 mm dia.) 45° truncated	W wire (100_m)	5 x 32 x 95	HIP diffusion
V2-02-15S	CuCrZr (Dual)	CuCrNb (1mm)	Ni	W (3.2 mm dia.) 45° truncated	W wire (100_m)	5 x 32 x 95	HIP diffusion
V2-02-15T	CuCrZr (Dual)	CuCrNb (1mm)	Ni	W (3.2 mm dia.) 45° truncated	W wire (100_m)	5 x 32 x 95	HIP diffusion
V2-02-15Q	CuCrZr (Dual)	CuCrNb (1mm)	Ni	W (3.2 mm dia.) 45° truncated	None	5 x 32 x 95	E-beam welding
V2-02-15R	CuCrZr (Dual)	CuCrNb (1mm)	Ni	W (3.2 mm dia.) 45° truncated	None	5 x 32 x 95	E-beam welding

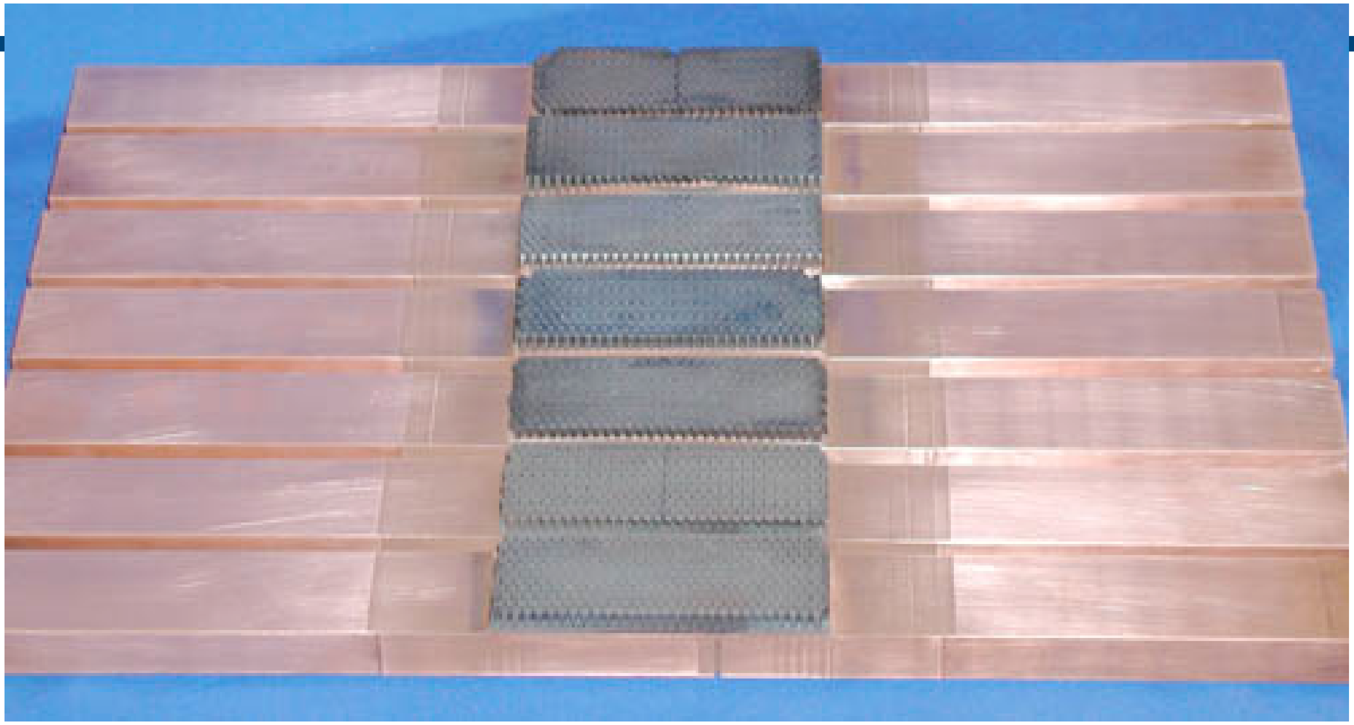
Honeycomb dam vs. W wire dam

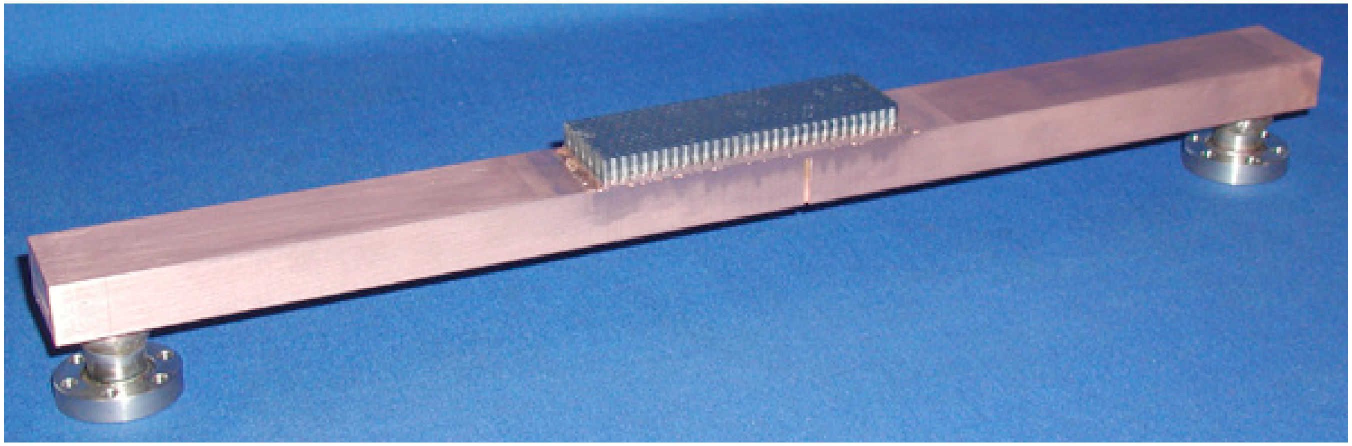






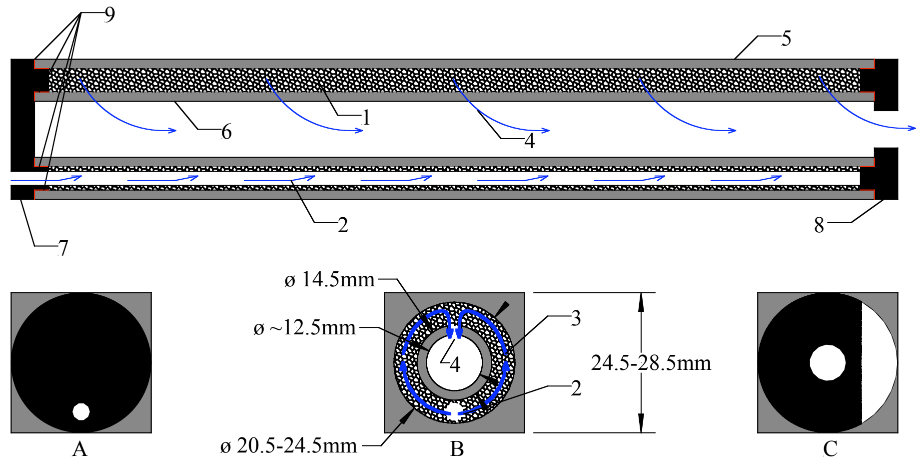


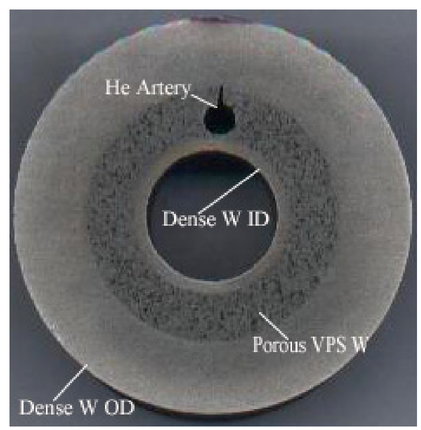


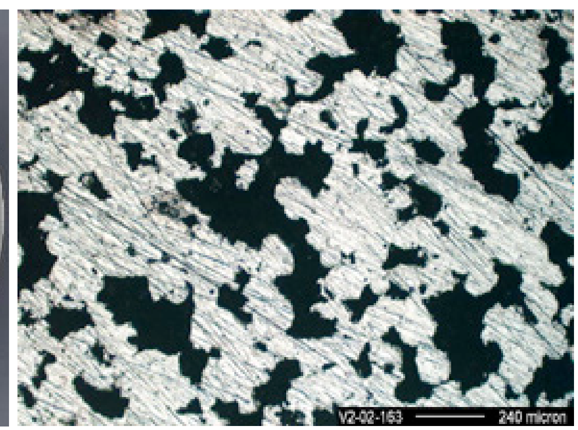


He Cooled Refractory Metal Heat Sink

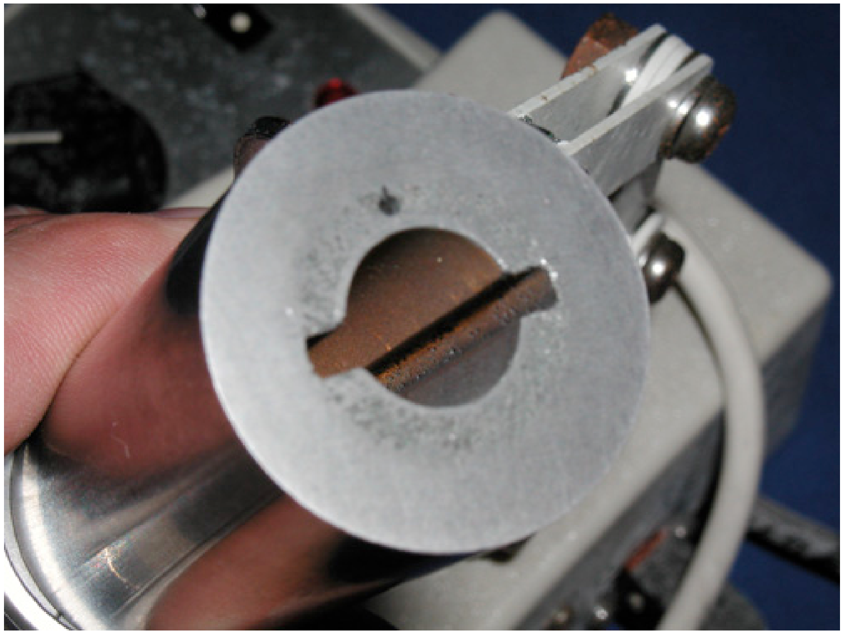
- Using removable mandrels and by controlling the deposition parameters, porous W deposits between dense W layers have been produced for use as helium cooled heat sinks.
- Porosity levels between 30-70% have been produced.
- Helium flow tests have demonstrated the porosity is interconnected.
- Size of porosity is dependent on the size of the starting powder.







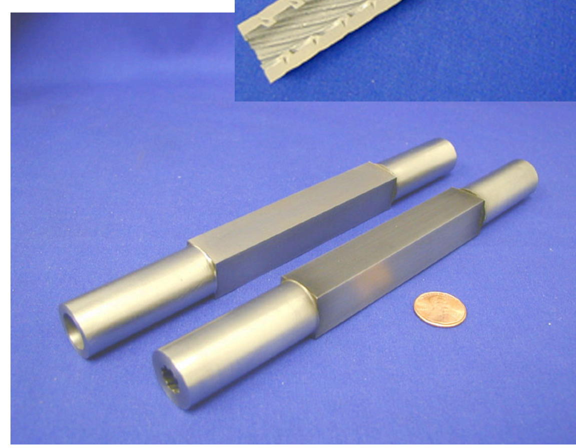
Spray Formed He Heat Sinks



Liquid Li Cooled Refractory Metal Heat Sinks

- Plasma facing component heat sinks with in-situ formed helical fins
- Machining of the negative configuration into a removable mandrel

ID Number	Material	Bore Configuration
V2000-20	W-Ni-Fe	Smooth
V2000-23B	W-Ni-Fe	Finned
V2000-3C	Molybdenum	Smooth
V2000-24	Molybdenum	Finned
V2002-12D	Tungsten	Finned



Liquid Li heat sinks after machining of TC holes and attachment of SS fittings

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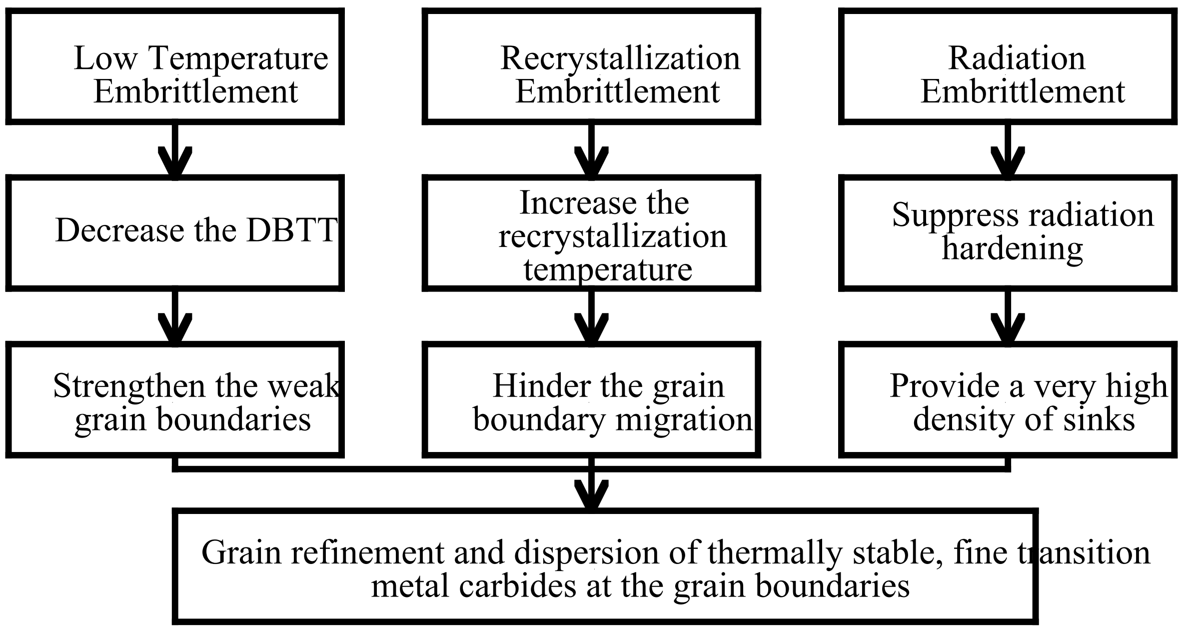
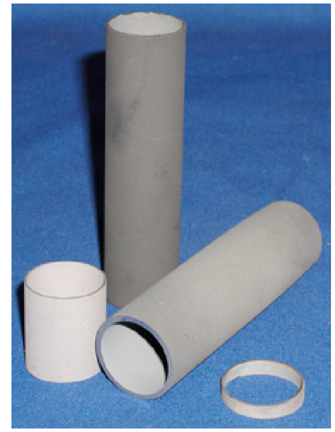
Nanograined W for Improved Resistance to Embrittlement

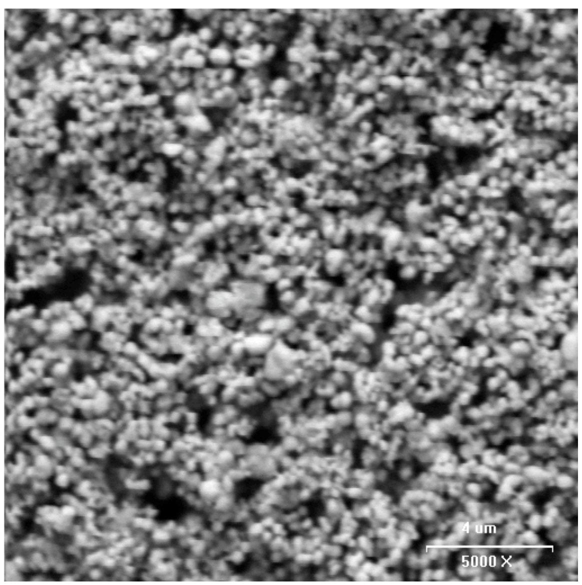
Prof. Kurishita of Japan identified the benefits of modifying W and Mo with transition metal carbides to achieve fine grain sizes. Potential benefits are improved ductility and resistance to embrittlement.

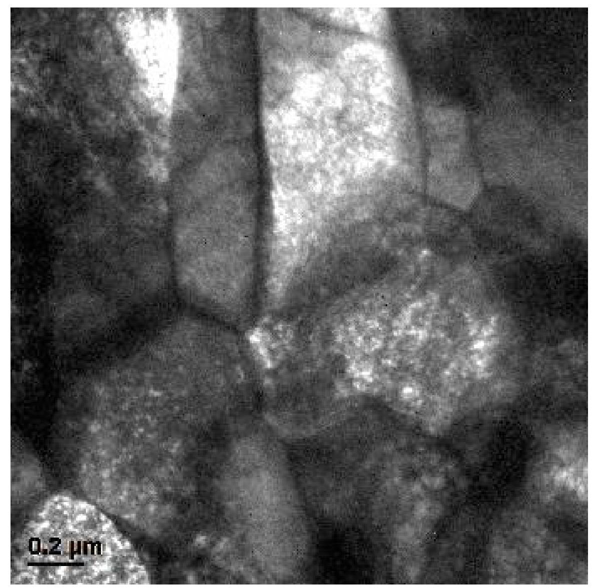


Fabrication of Nanograined W

- Submicron W powder (<0.5_m)
- Transition metal carbides to pin the grain boundaries (HfC)







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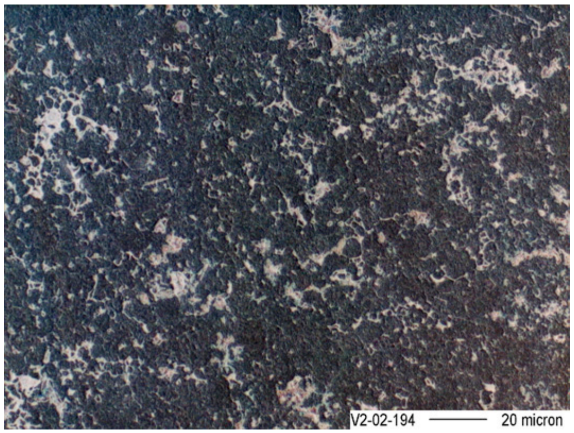
Effect of high temperature exposure on grain size for samples with and without HfC

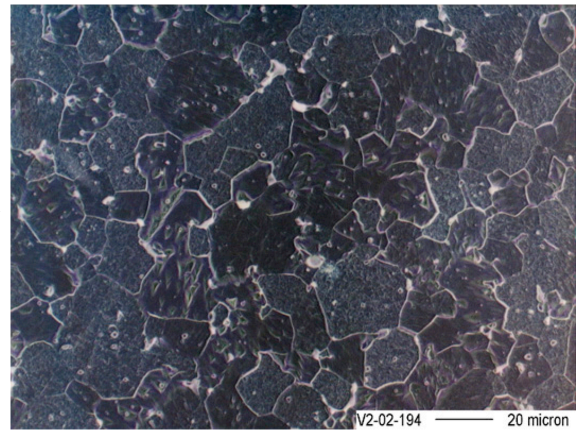
1750˚C, 24hrs

2300˚C, 4hrs

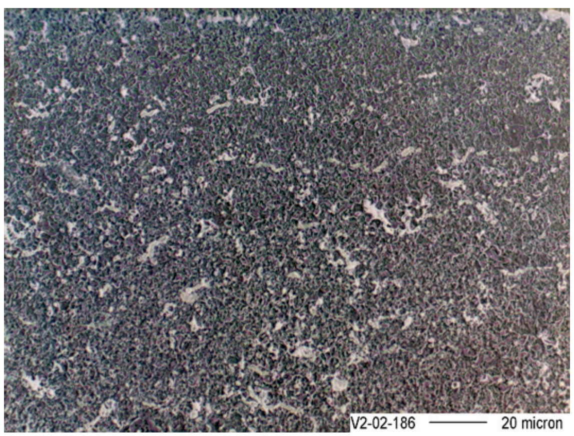
W (.5)
GS: 3_m



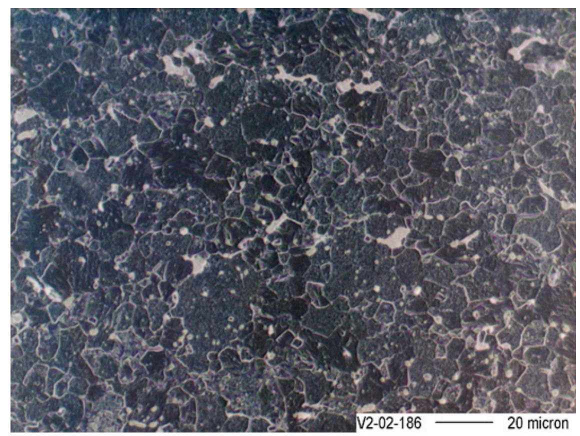
W (.5)
GS: 11_m



W (.5)-HfC
GS: <1_m



W (.5)-HfC
GS: 5_m



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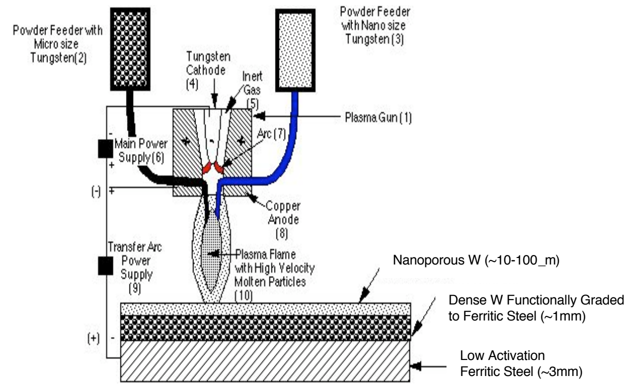
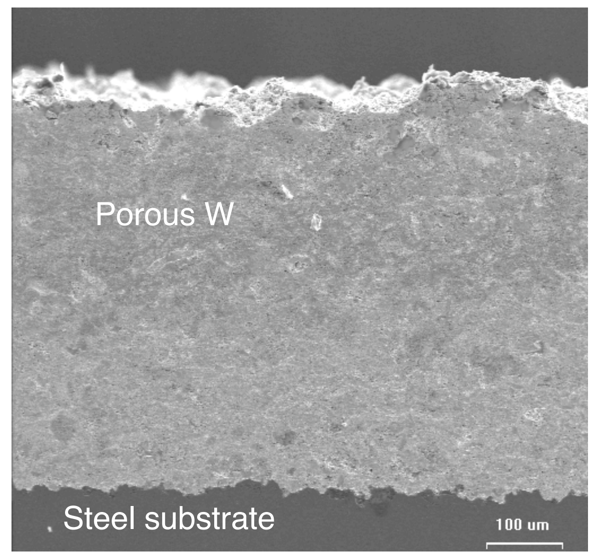
Nanoporous W Deposits on Steel Substrates for Laser IFE

- Steel substrates (25mm x25mm x 5mm)
- Coating thickness: 0.1-1.5mm
- By controlling the heat input to the individual particles, porosity values: 10-30%





SEM backscattered image of a porous tungsten deposit on a steel substrate

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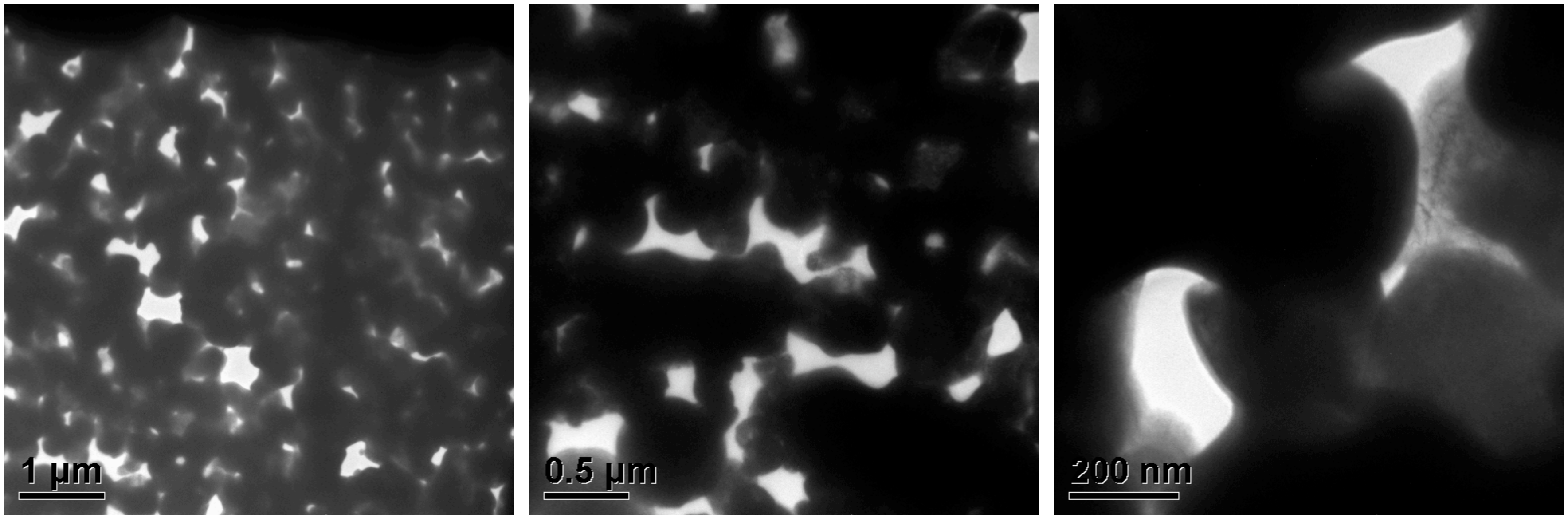
TEM Analysis of Porous Structure



- Bulk density is ~ 80%
- Distance between pores is ~500nm
- Testing verified the samples are permeable to He

Summary

- VPS forming techniques can be used to deposit armor materials on various substrate materials.
- Brush armored mockups have survived cyclic HHF testing at >20MW/m^2.
- Components can be produced with tailored microstructures
  - Grain size
  - Porosity
  - Alloys
  - Dispersion strengthened
  - Multiple layers