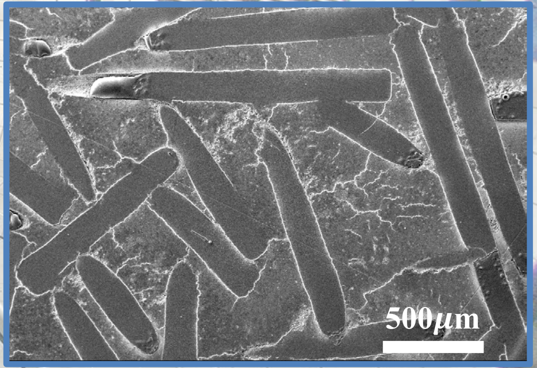
PMI Thrust: Testing of Novel Plasma-Facing Materials

DIII-D PIT Strategic Planning Meeting

Presented by J. Coburn on behalf of Plasma-Material Interactions topical group

September 14th, 2023



DIII-D NATIONAL FUSION FACILITY

Sandia National Laboratories

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U.S. DEPARTMENT OF ENERGY

NNSA

PMI Thrust: Testing of Novel Plasma-Facing Materials

- **Long range goal:** promote testing of a wide variety of plasma-facing material (PFM) candidates under FPP-relevant conditions
  - Looking more towards complex material solutions and mixed material environments
  - Down-selection of materials with improved PMI and thermo-mechanical properties:
    - Erosion resistance, heat flux handling, recrystallization, thermal shock, recycling, fuzz, …
- **Why DIII-D? Why now?**
  - DIII-D combined high heat and particle fluxes in tokamak environment, along with multiple material exposure options (DiMES, MiMES, wall tiles)
    - **DIII-D is currently the best US option for comprehensive materials testing**
  - Aligns with DIII-D Five-Year Plan and various community reports (APS-CPP, FESAC 2020, NASEM) that explicitly call for **testing novel solid PFC candidates**
  - Presence of carbon limits some scope (retention) but not majority of near-term testing needs
- **Impact:**
  - Viable options for a new generation of divertor and blanket materials for FPP development
  - Vital stepping stone for full-component testing called for in DIII-D 5YP
  - **"Fusion materials and technology… set the timescale on which any FPP could be successful"** - CPP

PMI Thrust: Testing of Novel Plasma-Facing Materials

Issues & limitations of PMI experiments in past campaigns

- **Historically been limited by run time guidance**
  - Team members do their best to augment this limitation through combining proposals, piggyback time, and Director's Reserve applications
  - Combined expts with little runtime severely limits the 'material evaluation' part of AME
-

Will testing a small selection of new materials each campaign address the near-term needs for FPP development? Likely not

- **Necessary preparation time for first-of-a-kind materials (~months - year)**
  - It's difficult to convince researchers to spend 6 months manufacturing and preparing specialized samples if there's no guarantee of run time. Means that sample prep usually starts after lengthy ROF process → limits ability to perform expt at start of campaign

PMI Thrust: Testing of Novel Plasma-Facing Materials

Benefits of Thrust Status

- **More materials! More collaborators! More physics studies! More good science**
  - **The demand is there**. If DIII-D allocates 5+ days for PMI, the fusion community has enough materials
  - Dedicated time to utilize full capabilities of DIII-D → more in-depth physics studies
    - **Heated DiMES for PMI response at elevated starting temperatures → stepping stone for heated div. (5YP)**
    - **Multiple spectroscopy measurement techniques**
    - **Varied DiMES designs / sample geometries**
- **Alleviates load for writing individual MPs for short material exposure experiments**
  - More time for sample prep and ability to slot in collaborator materials
- **Opportunity to optimize exposure scenarios for similar experiments**
  - First 1/2 – 1 day to build proper reusable references? H-mode w/ ELMs, low-power L-mode, etc.
  - Experiments of greater risk (impurities) can be combined and scheduled before a vent
- **Important timing for testing 'beyond ITER' materials for FPP development**
  - Nicely balances other PMI thrust that supports ITER R&D needs
  - DIII-D is important 'piece of the puzzle' for qualifying materials in an integrated environment, in addition to single-effect or linear plasma studies

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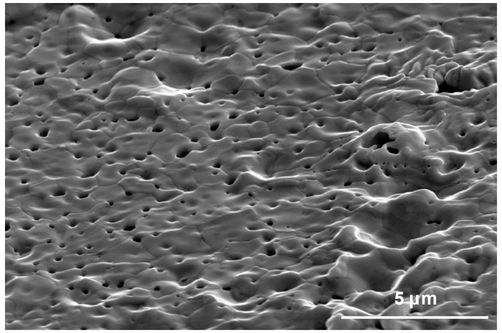
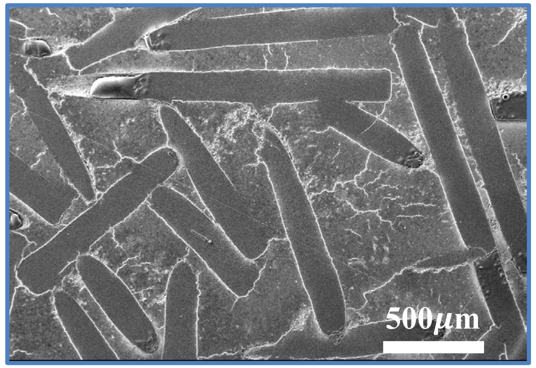


W with TiO2 dispersoids, post exposure (SNL)

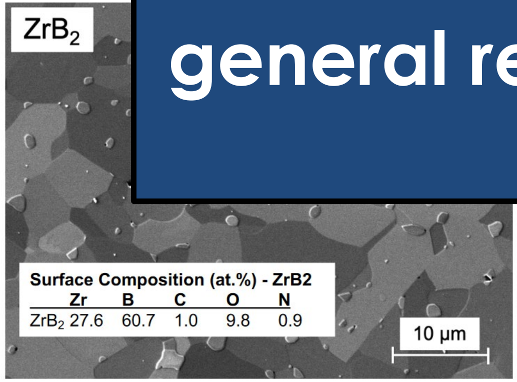
GA	Functionally graded materials, W-fiber composites, SiC/ceramics
National Labs	UHTCs, HEAs, Dispersoids, W alloys
Universities	SiC/ceramics, 3D-printed W, UFG W
Industry	11+ companies: W Heavy Alloys, others?

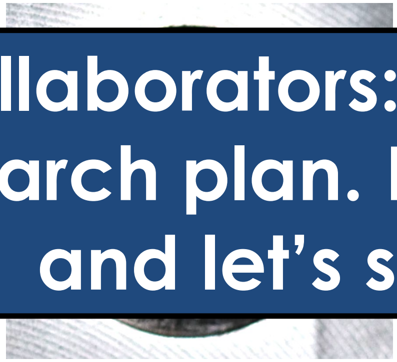


posure

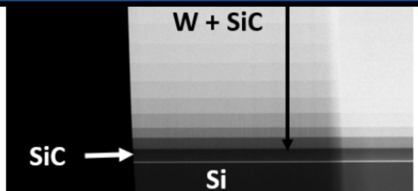
pr

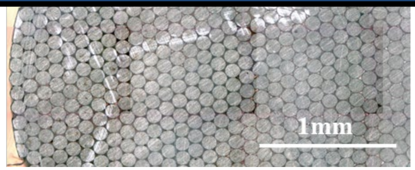
PMI to collaborators: "We have time for you and a general research plan. Bring your best materials to DIII-D and let's see what happens!"





Additively-manufactured W, post-exp (ORNL)



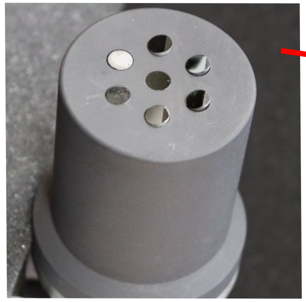


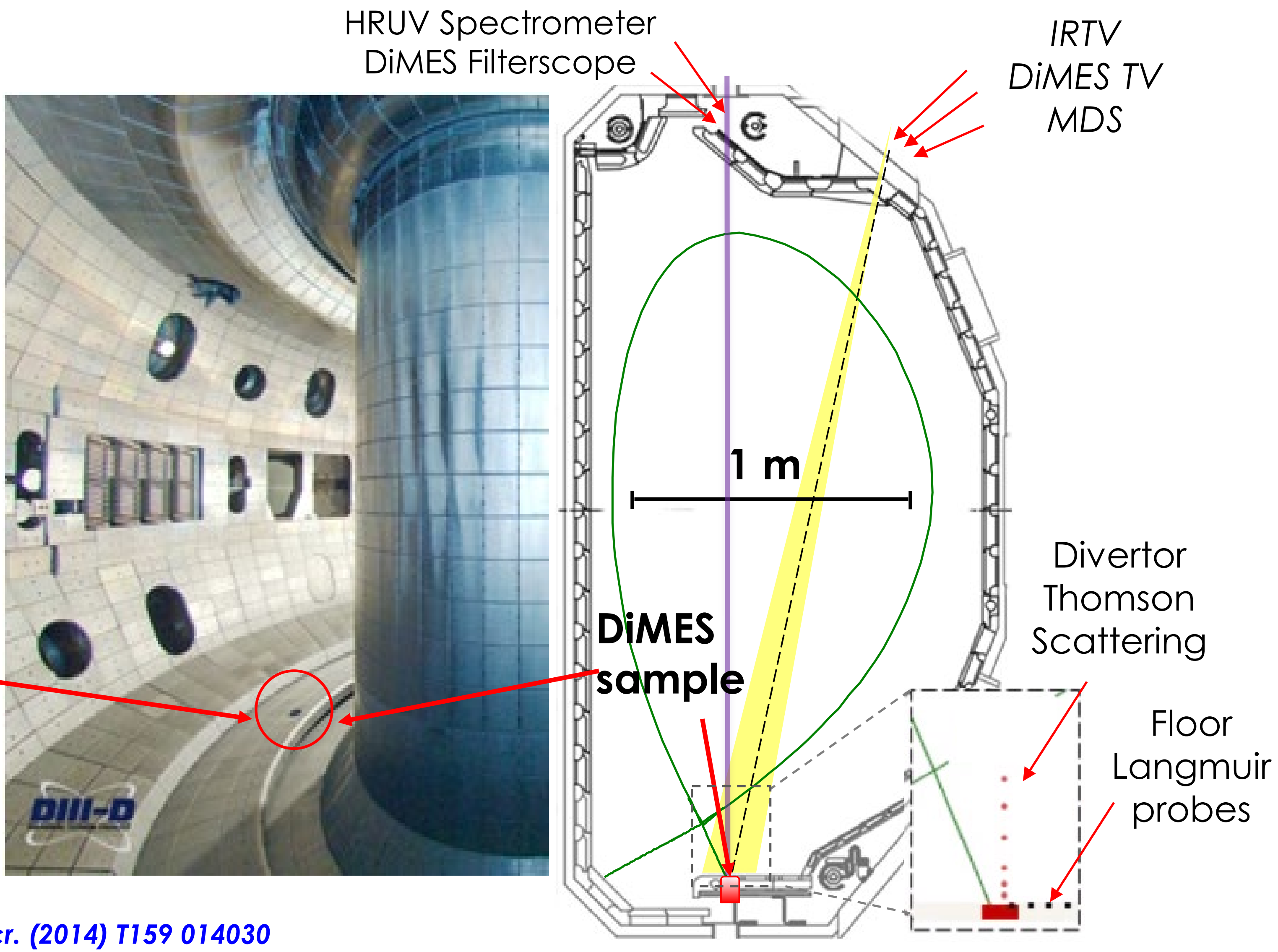
ured W,
posure
ulich)

Supplemental

Divertor Material Evaluation System (DiMES) at DIII-D

- Pre-characterized samples are exposed in the lower divertor of DIII-D tokamak using DiMES
- Samples are typically inserted flush with the divertor tile surface
- Outer strike point (OSP) can be swept over samples or dwell on them
- Samples imaged by filtered CMOS and CCD cameras and a high-resolution MDS and UV spectrometers
- Plasma parameters measured by Divertor Thomson Scattering (DTS) and Langmuir Probes (LPs)
- Post exposure sample imaging & analyses

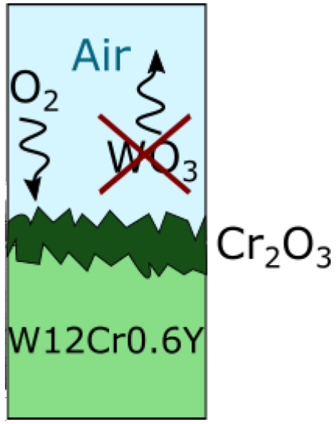




[1] D. Rudakov et al., Phys. Scr. (2014) T159 014030

Posters: H. Schamis et al, ID:178; D. Rudakov et al., ID:218; L. Capelli et al., ID:189 ; D. Ennis et al., ID:194

Current Avenues of Fusion Mat. Development: Tungsten

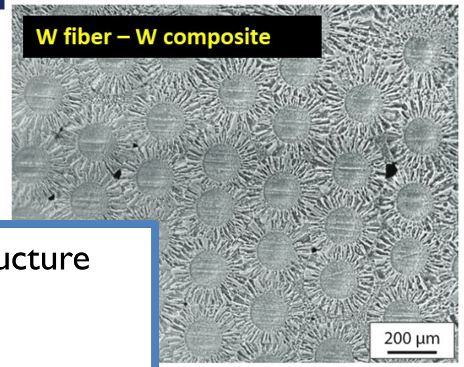


Oxidation

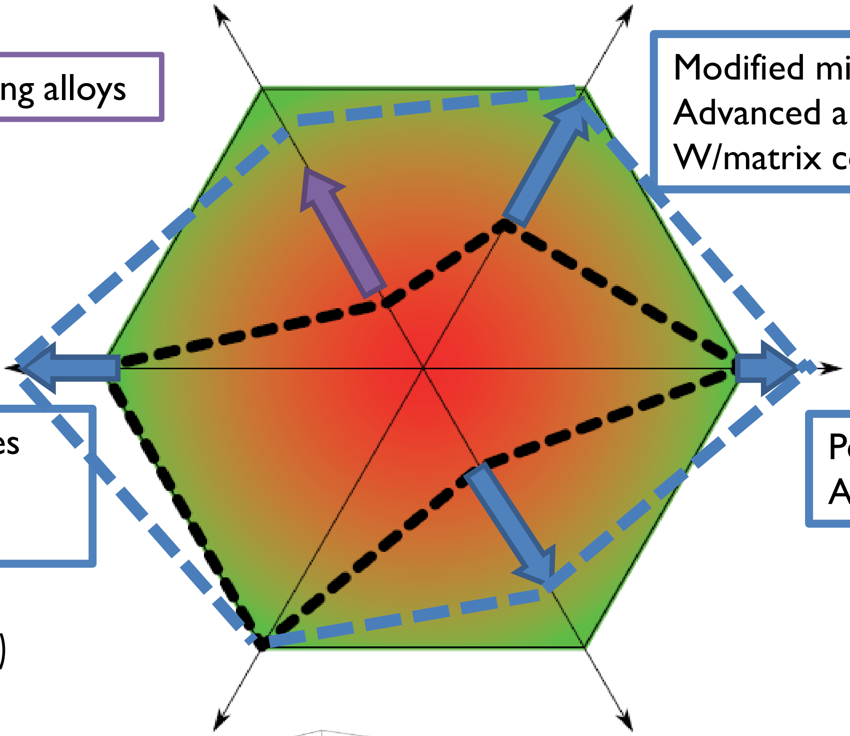
Self-passivating alloys

Mechanics

Modified micro/nano-structure
Advanced alloys
W/matrix composites



Dispersion-Strengthened Tungsten

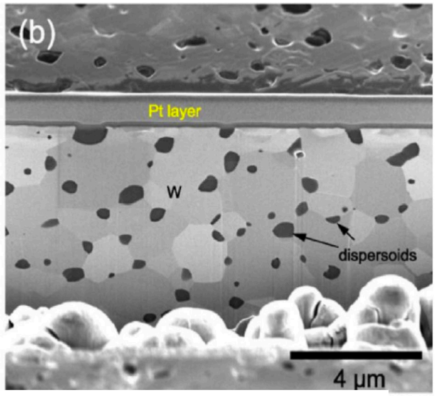


Thermal Properties

Advanced alloys & composites
Additive manufacturing
Component optimization

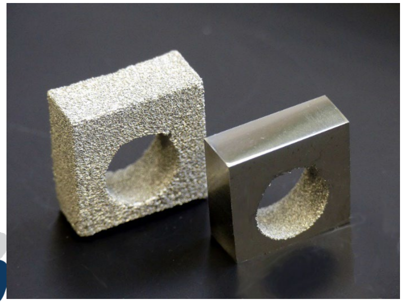
D/H/T Interaction

Permeation barriers
Alloy compositions

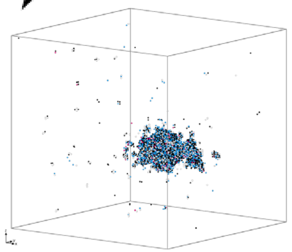


AM divertor component with W plasma-facing tiles (ORNL)

High-density AM W (Julich)



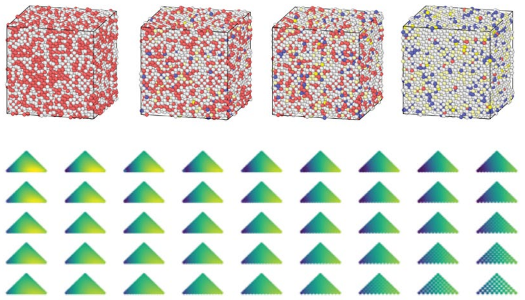
Sputtering



Rad damage in W-Ta alloy

Transmutation/ Activation

Radiation Analysis
AI/ML materials optimization



High-entropy alloy compositions (FeNiCrCoMn)

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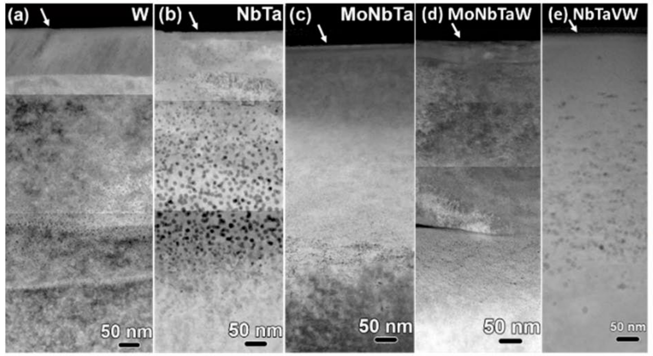
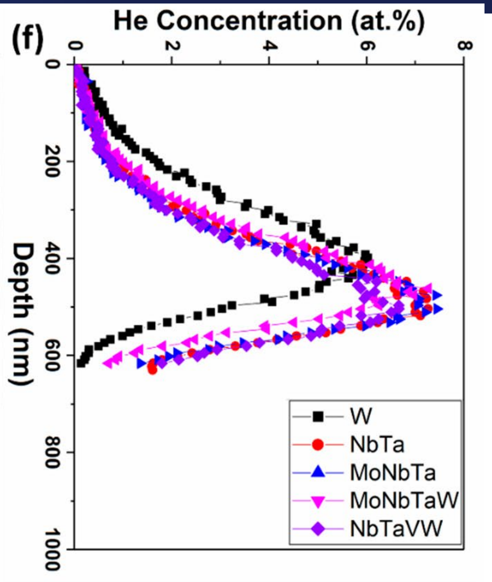
Current Avenues of Fusion Mat. Development

Other (non-W) areas of research

- **Self-passivating alloys (for oxidation resistance)**
- **High-entropy alloys (for neutron damage resistance)**
- **Additive manufacturing (for component fabrication)**
- **Ultra-High Temperature Ceramics (for mechanical properties)**
- **Functionally-graded materials (PMI + neutron resistance)**





Additively manufactured high-entropy alloys for He irradiation

E. Lang, Nanomaterials 2022, 12, 2014

Common Theme:

- **Researchers are looking more towards complex material solutions and mixed material environments, including interactions with other plasma species (He, low-Z coatings, N, etc.)**

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