

Virtual Laboratory for Technology FES FY2017 Second Quarter Report

Phil Ferguson
for the VLT members



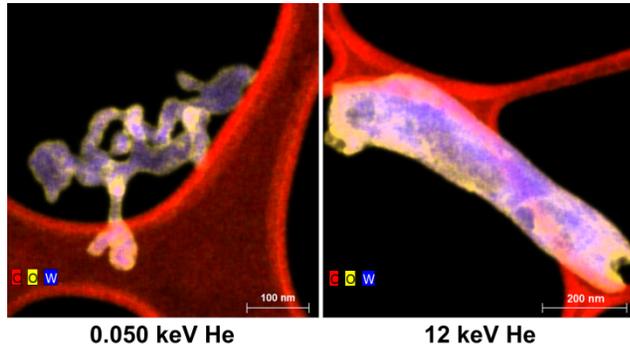
Director's Corner

- Bi-monthly teleconferences have been continuing with good representation.
- The VLT has discussed both the National Academies Study and the FESAC Transformative Enabling Capabilities Subcommittee activities in recent teleconferences.
 - Input format has only recently been released for the FESAC subcommittee.
- The VLT is preparing information to participate in FES budget planning discussions. This is a new activity for the VLT, and we are working to provide information that will be useful to our program managers.
- This and future highlights will continue to cover research highlights from the recent VLT publications and the following main VLT research areas:
 - Magnet Systems; Heating & Current Drive; Plasma Fueling/ ELM Pacing/Disruption Mitigation
 - Plasma Facing Components; Plasma Materials Interactions; Structural Materials
 - Design/Systems studies; Power Handling; Fusion Safety; Fuel Cycle Research; Blanket Technology; Vacuum Systems

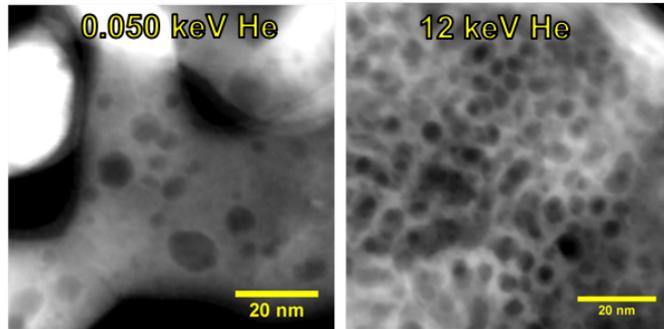
If you have any questions on the information in this report, please don't hesitate to contact us.

Tungsten nanotendrils depend on energy of bombarding helium ions

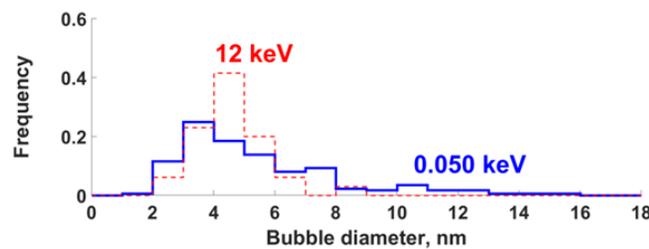
Nanotendrils characterization



X-ray mapping and electron diffraction find both low- and high-energy growth produces tungsten nanocrystals with a thin surface oxide



STEM images of low- and high-energy grown tendrils allows comparison of bubble size distributions.



Scientific Achievement

Tungsten exposed to both high and low energy helium bombardment showed qualitatively similar nanotendrils formation, but with different grain size and bubble distributions.

Significance and Impact

Future advanced plasma-facing materials must be engineered to resist steady-state plasma and plasma disruptions; this research determines the growth structures of tendrils under helium energies simulating both conditions.

Research Details

Scanning and transmission electron microscopy were used in conjunction with electron nanocrystallography to illuminate differences in tendrils morphologies and bubble distributions in 50 eV and 12 keV helium-exposed tungsten

Application

Determination of growth structures under different plasma-exposure conditions will provide baseline information for modeling, and help future materials engineering efforts to mitigate plasma-induced degradation.

K. Wang, R.P. Doerner, M.J. Baldwin, F.W. Meyer, M.E. Bannister, A. Darbal, R. Stroud, C.M. Parish, Morphologies of tungsten nanotendrils grown under helium exposure, *Scientific Reports*, 7 (2017) 42315 (Early Career Award research program)

Interaction of Tungsten Interstitial Clusters with Transmutants Re, Os, and Ta

Science Objective

Develop a model of binding energies of tungsten (W) interstitial clusters with solute transmutation products, most notably Re, Os, and Ta, to inform larger length and time scale simulations.

Why it Matters

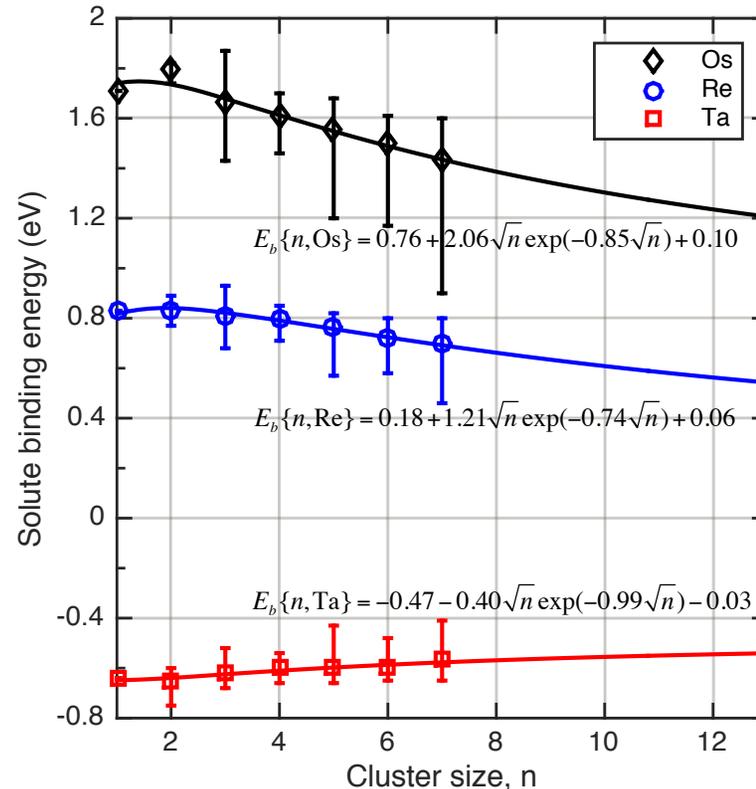
Transmutation products critically influence the nucleation and evolution of various defect microstructures and precipitates that determine the properties of W-based plasma-facing materials.

Method

VASP software used to perform calculations based on the *ab initio* density functional theory method. 15 million core hours used, 1300 gigabytes of data produced.

Wahyu Setyawan, Giridhar Nandipati, and Rick Kurtz,
Journal of Nuclear Materials 484 (2017) 30-41.

<http://dx.doi.org/10.1016/j.jnucmat.2016.11.002>



Binding energies for size- n W-interstitial clusters with Re, Os, or Ta atoms. Bars indicate maximum and minimum values. Positive binding energies are attractive. Solid lines show model analytical equation results.

Long-time Atomistic Dynamics through new self-adaptive Accelerated Molecular Dynamics Method

Science Objective

Develop a new self-adaptive accelerated molecular dynamics (MD) technique to accelerate the MD associated with rare events on rugged potential energy surfaces.

Why it Matters

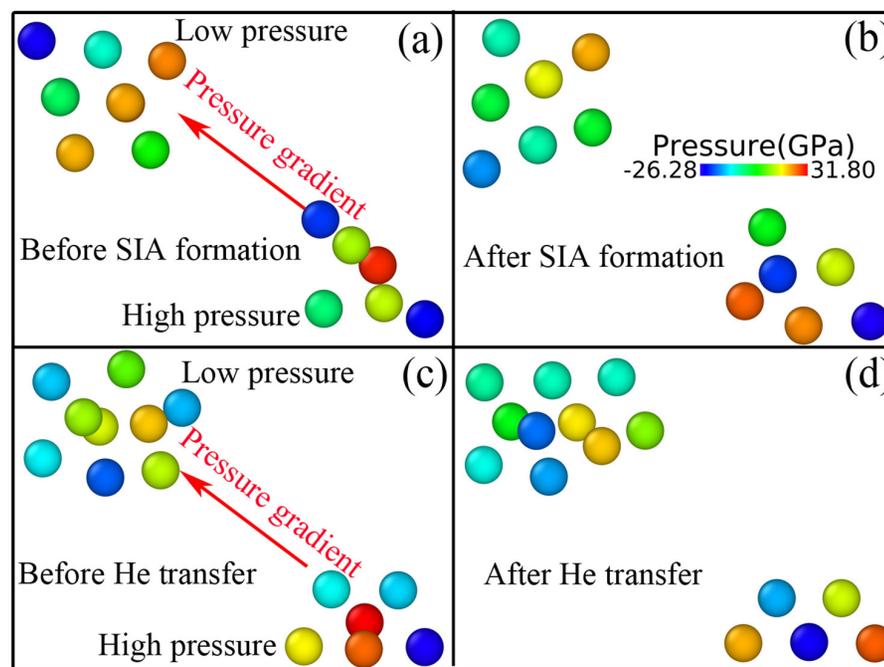
Many microscopic events of interest in radiation materials science occur on a time-scale of seconds or longer and the challenge of dealing with these rare events is beyond the capability of conventional MD methods.

Method

A boost potential based on total atomic displacement at a given temperature is used to accelerate the transition of the system between different local minima by following transition-state theory.

Ning Gao (IMP), Li Yang (UEST), Fei Gao (UM), Rick Kurtz, Damien West (RPI), and Shengbai Zhang (RPI), *Journal of Physics Condensed Matter* 29 (2017) 145201.

<https://doi.org/10.1088/1361-648X/aa574b>



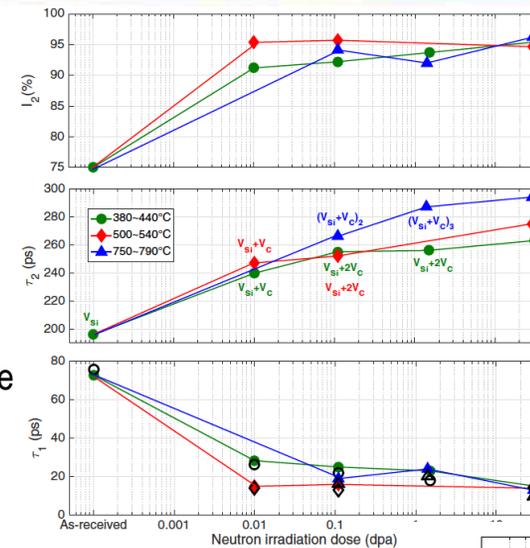
He cluster growth by Ostwald ripening. The pressure gradient between two He-vacancy clusters in Fe is depicted. (a) and (b) show the atomic configurations before and after the formation of a single interstitial. (c) and (d) are the atomic configurations before and after transfer of a He atom from the smaller to the larger cluster. Each He atom is colored according to its maximal principle stress, as indicated by the color bar in (b).

Positron annihilation measurements of neutron irradiated SiC reveal insight on vacancy population

Research Highlight

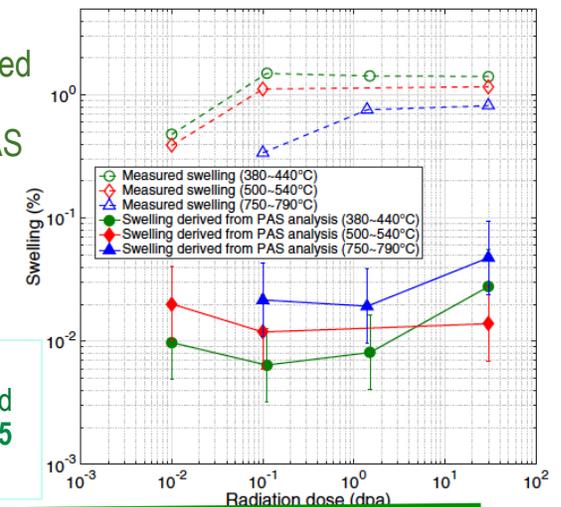
Scientific achievement

- Positron annihilation lifetime spectroscopy was used to measure the vacancy defects in SiC following neutron irradiation from 0.01 to 31 dpa, as a function of irradiation temperature from 380 to 790 °C.
- The neutral and negatively charged vacancy clusters were identified and quantified, indicating that vacancy-cluster induced swelling **can not** explain experimentally measured swelling in this transient, saturating swelling regime, and are consistent with identification of anti-site defects.
- **Significance and Impact**
- These positron measurements and analyses exclude the possibility that large vacancy clusters are generated in these neutron-irradiated SiC specimens in the temperature range from 380 to 790 °C, and suggest that more work is needed to elucidate the underlying mechanisms controlling the swelling of SiC exposed to neutron irradiation.
- **Research Details**
- Positron annihilation lifetime spectroscopy and coincident Doppler broadening measurements performed at ORNL in the Low-Activation for Materials Development and Analysis (LAMBDA) laboratory at ORNL on SiC specimens neutron irradiated in HFIR



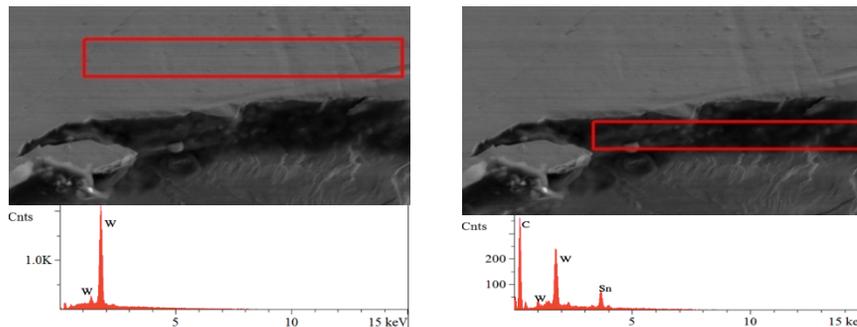
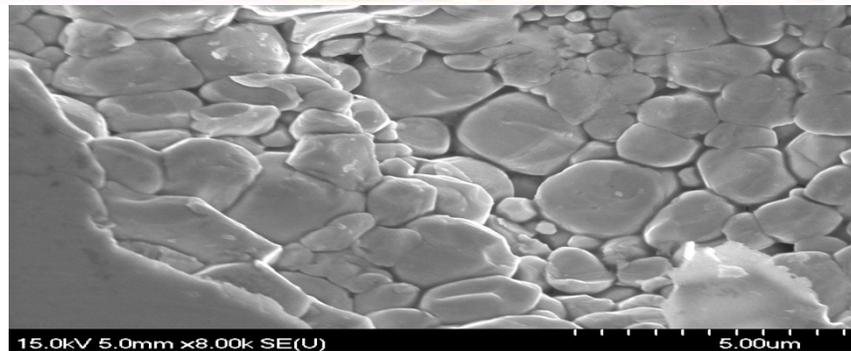
Short (τ_1) and long (τ_2) positron lifetime and associated intensity of long-lifetime component (I_2) of neutron irradiated SiC as a function of T_{irr} and neutron dose. Characteristic vacancy clusters consistent with measured lifetimes are identified

Experimentally measured swelling (dashed line) versus derived from PAS analysis (solid line)



Publication:
X. Hu, T. Koyanagi, Y. Kato, and B.D. Wirth, *Physical Review B* 95 (2017) 104103

Innovating adaptive PMI with porous refractory metals combined with liquid-metal-solid hybrid nanocomposites



- a) Top picture shows porous tungsten produced at U. Illinois via spark plasma sintering (in collaboration with Dr. Jessica Krogstad, MSE U. Illinois)
- b) Bottom pictures show Sn below sample surface, indicating liquid metal mixing with structured (fuzz) tungsten surface

Scientific Achievement

This work examined liquid metal mixing with structured surfaces for possible hybrid PFC

Significance and Impact

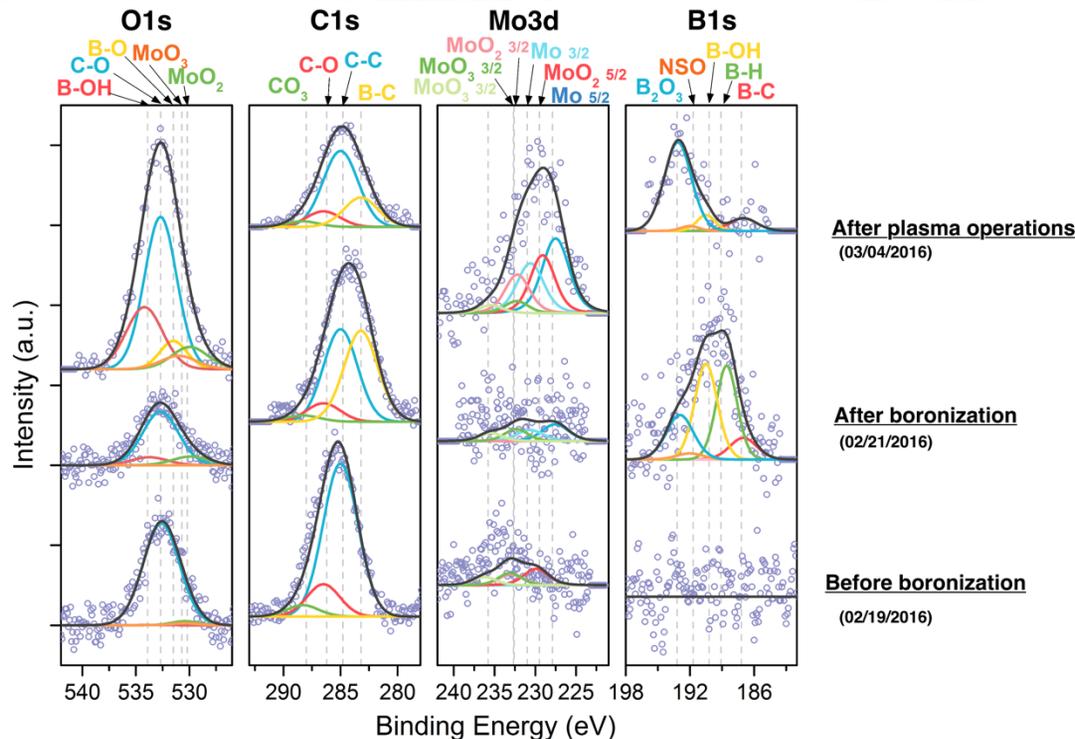
This work further demonstrated that liquid metal is more resistant to emission/ejection from a structured surface, compared to a smooth surface, allowing for the utilization of a liquid metal as a PFC within a porous tungsten scaffold

Research Details

- Previous work on refined grain tungsten demonstrates grain boundaries acting as vacancy sinks for He-vacancy complex. Utilize increased surface-area-to-volume ratio of porous tungsten as vacancy sink
- Currently examining adaptive PMI properties: self-healing during high-heat flux exposure and understanding of retention properties

E. Lang, A. Kapat, J.P. Allain, Submitted to Nucl. Mater. And Energy (2016)

in-situ analysis of boronized high Z samples with MAPP in NSTX-U



XPS spectra collected in situ with MAPP with a boronized TBM sample. The labels in the upper part of the panels identify the regions, while the labels to the right describe the modifications that the sample has undergone in NSTX-U.

Analysis of surface chemistry of boronized TBM samples in NSTX-U between plasma exposures, H Schamis, F Bedoya, et al. 58th Annual Meeting of the APS Division of Plasma Physics, October 31-November 4, 2016 San Jose, CA

Scientific Achievement

This work shows in-situ data collected in NSTX-U with MAPP on high-Z substrates. For the first time the interaction of low Z coatings with high Z substrates in a tokamak has been measured inside a tokamak with XPS.

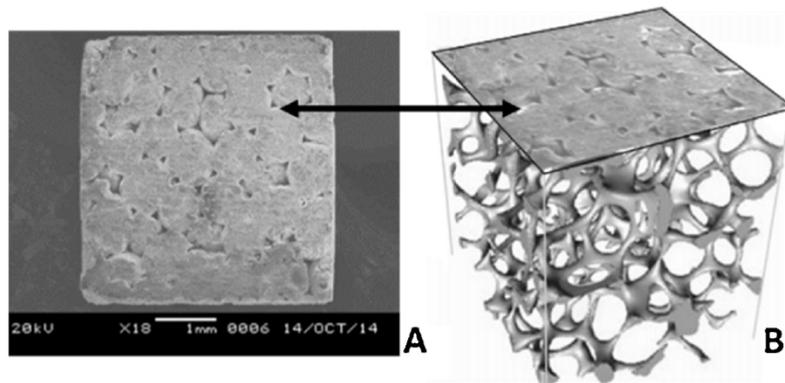
Significance and Impact

We measured the evolution of the chemistry of boronized TBM samples exposed to D plasmas in NSTX-U. This work will provide the basis to analyze the evolution of PFCs in NSTX-U following the upgrade to high Z materials included in the next 5 years plan.

Research Details

- The XPS data showed to chemical interaction of B and the TBM substrate, rather, complete coverage of the latter following boronization. The coatings however, are removed and oxidized with exposure to plasmas. As in the case of ATJ graphite samples, oxygen seems to play a very relevant role on the chemical evolution of high Z substrates.

Development of a new cellular solid breeder for enhanced tritium production



A–B: SEM image of cellular breeder (A) and tomography scan showing network of interconnected micro-channels (purge channels) within (B).

S. Sharafat, B. Williams, N.M. Ghoniem, A. Ghoniem, M. Shimada, and Alice Ying, “Development of a new cellular solid breeder for enhanced tritium production,” *Fusion Engineering and Design* **109–111** (2016) 119–127.

Scientific Achievement

A new cellular solid breeder is presented with 2 to 3× the thermal conductivity and substantially higher density (~90%) compared with pebble beds

Significance and Impact

Development of a robust cellular breeder for tritium production will enable more efficient and reliable blanket designs.

Research Details

- The cellular solid breeder contains an internal network of interconnected open micro-channels (~50 –100 μm diam.) for efficient tritium release.
- Cellular breeders are made by melt-infiltrating Li-based ceramic materials into an open-cell carbon foam followed by removal of the foam.
- High temperature (750 °C and 40 °C/mm) cyclic compression tests demonstrated good structural integrity (no cracking) and low Young’s modulus of <5 GPa.
- Deuterium absorption–desorption release rates were comparable with those from pebble beds with similar characteristic T-diffusion lengths.



U.S. DEPARTMENT OF
ENERGY

Office of
Science



Planning experiments and pre-experimental analysis for mixed-convection MHD flows using MaPLE facility at UCLA

Why it matters

Multiple effects associated with MHD buoyancy-driven flows are critically important to development of all LM blankets. MaPLE facility upgrades, experimental planning, and pre-experimental analysis are underway to study MHD mixed-convection flows relevant to family of PbLi blankets.

Approach

3D numerical computations (using state-of-the-art HIMAG code) of MHD flows with heating in conditions of the PbLi experiments in MaPLE facility, including: *upward* and *downward* flows, velocities 0.01-0.2 m/s, magnetic field up to 1.8 T and surface heating up to 0.4 MW/m².

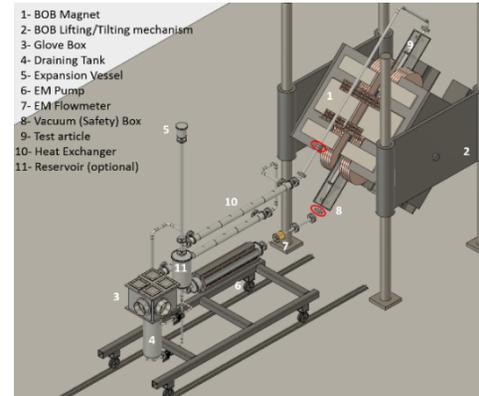
Results

Upward flows: 3D computations suggest strong buoyancy effects in the form of a high-velocity jet near the heated wall.

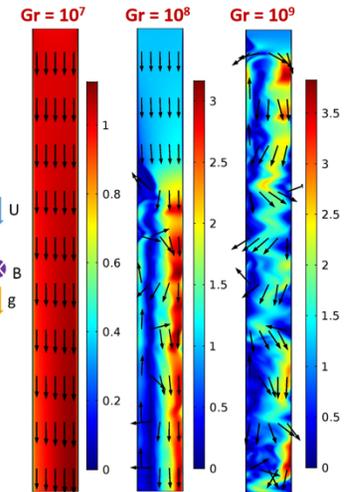
Downward flows: reverse flow zones and MHD instabilities.

Publications

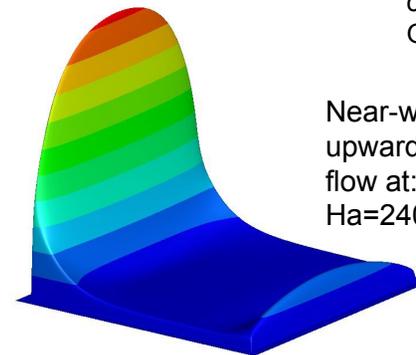
S. Smolentsev, M. Abdou, C. Courtessole, G. Pulugundla et al., *Review of recent MHD activities for liquid metal blankets in the US*, Magnetohydrodynamics. Accepted, 2017.



Schematics of upgraded MaPLE loop and the magnet system with tilt and lift

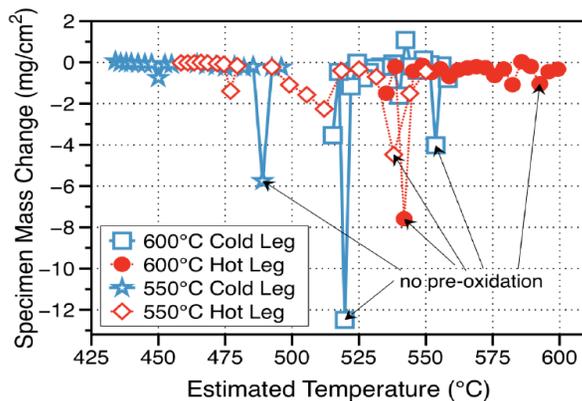
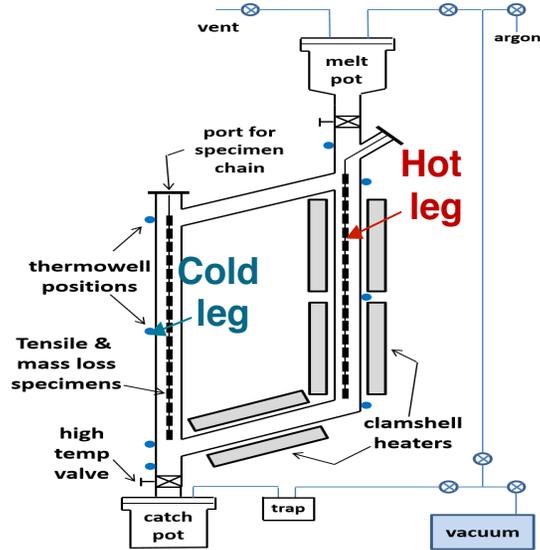


Instabilities in the MHD mixed-convection downward flow as Gr number increases



Near-wall high-velocity jet in the upward MHD mixed-convection flow at: Re=5500, Gr=10⁹ and Ha=240

ORNL work on aluminum containing steels may extend temperature limits for PbLi fusion blankets



Challenge

Ferritic and Martensitic stainless steels have limited compatibility with PbLi eutectic liquid, the preferred breeding and cooling medium in US reactor designs. Extending the service temperature limits may be possible with Al-containing steels.

Experiment Design & Operation

Two thermal convection loops were operated with eutectic PbLi for 1000 h at peak temperatures of 550 and 600°C. Commercially available Kanthal alloy APMT (Fe-21Cr-5Si-3Mo) was used as surrogate for fusion-relevant alloys under development. During operation, APMT tensile specimens were exposed to PbLi in hot and cold legs of the loop (upper figure).

Achievement

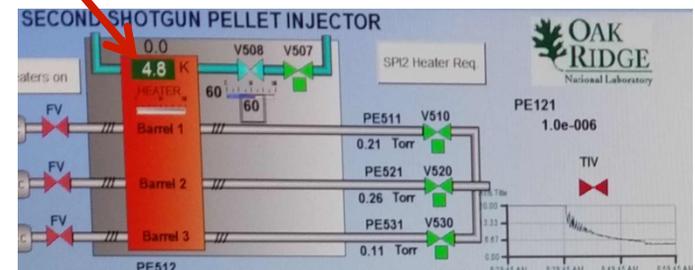
The mass loss of pre-oxidized APMT was significantly lower than APMT without oxidation, showing that an aluminum oxide surface can improve the alloy compatibility with PbLi (lower figure).

Future directions

The third loop in this series is being assembled, for operation with peak temperature of 650°C.

First Pellets Fired in New ITER-like Shattered Pellet Injector Installed on DIII-D for Disruption Mitigation Studies

- A three-barrel shattered pellet injector (SPI2) was fabricated and tested at ORNL for use on DIII-D in support of the ITER disruption mitigation system
 - Based on the SPI design developed for ITER
 - Tested at ORNL producing pure D₂, Ne, and mixed D₂/Ne pellets of 7 and 8.5 mm diameter
- Installation on DIII-D was completed in 1QFY2017
- Commissioning in Mar 2017 obtained the first pellets fired into an empty DIII-D vessel
 - Temperatures of 4.8K achieved with steady LHe flow from a new dewar and transfer line
 - Pellets of D₂ and neon formed in 7 minutes
 - Pellet mass diagnostics show intact pellets reaching the shatter tube
- Key experiments for ITER disruption mitigation issues are planned
 - DIII-D remains the only machine with SPI and now has 2 systems to study simultaneous injection from multiple locations
 - Experiments on thermal mitigation and runaway electron dissipation will be performed in 2017



U.S. ITER/ORNL has responsibility for the ITER disruption mitigation system.



Theory and Experimental Measurement of Elliptical Polarization in ECH Transmission Lines Critical for ITER (MIT/USIPO)

Scientific Achievement

This research is the first to both measure the elliptical polarization of a pair of grating polarizers of non-rectangular profile and to successfully compare the results with the predicted polarization from a detailed numerical calculation.

Significance and Impact

ECH power, transported through highly oversized corrugated metallic waveguides, must achieve a specific elliptical polarization in order to be launched and absorbed as needed in ITER. These new results greatly expand our confidence in our ability to achieve the necessary desired polarization.

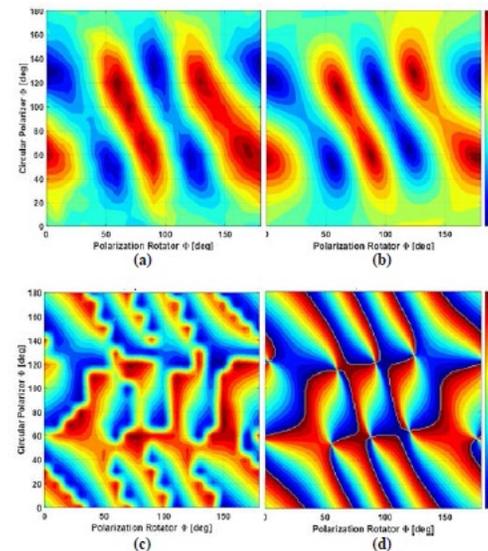
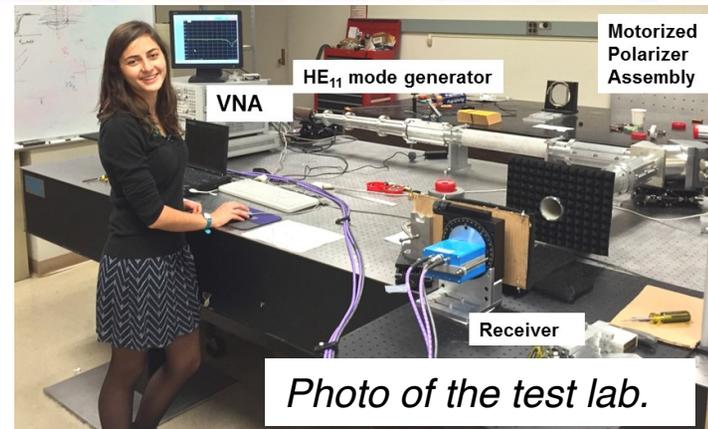
Research Details

- The polarization is measured using a 170 GHz VNA system at MIT and 63.5 mm waveguides and polarizers built by General Atomics and on loan to MIT from the US ITER IPO.
- The theory is calculated using the HFSS and CST codes for the exact shape of the grating grooves..

Application

These results are critical to designing the ITER ECH transmission lines but also apply to all other ECH experiments.

MIT: H. Hoffmann, S. Jawla, M. Shapiro and R. Temkin;
G. Hanson, US-ITER; supported by DOE VLT and US IPO



Comparison of experimental polarization results (left) with theoretical results (right); agreement is very good



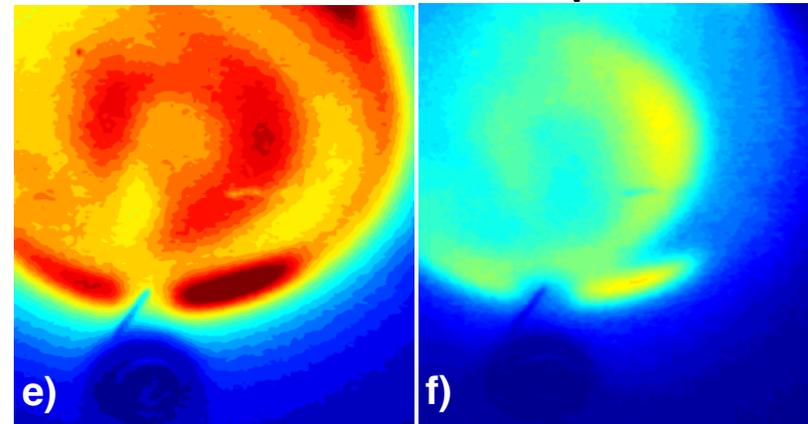
Electron heating with 28 GHz microwaves achieved in Proto-MPEX

- Installation of reflector cone and reduced pressure helped to improve electron heating with launch angle of -30 degrees.

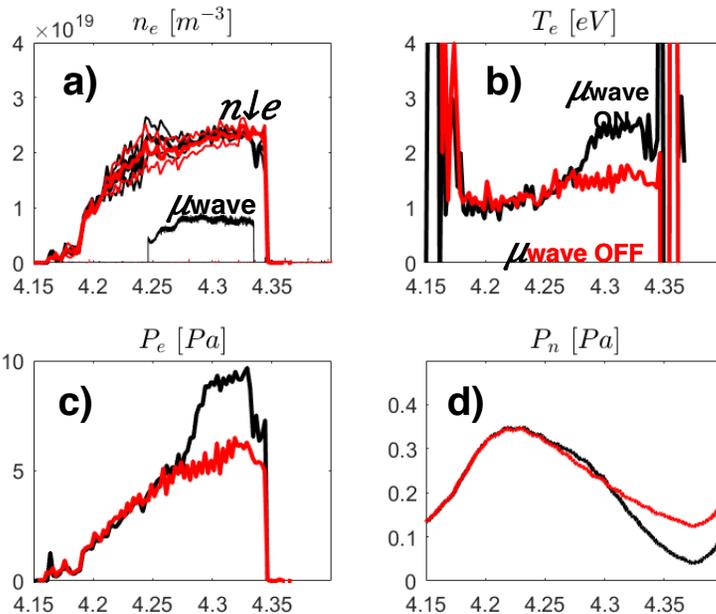


- 100 kW of helicon power
15 kW 28 GHz ECH power.

28 GHz μ Wave ON (~15 kW) 28 GHz μ wave OFF

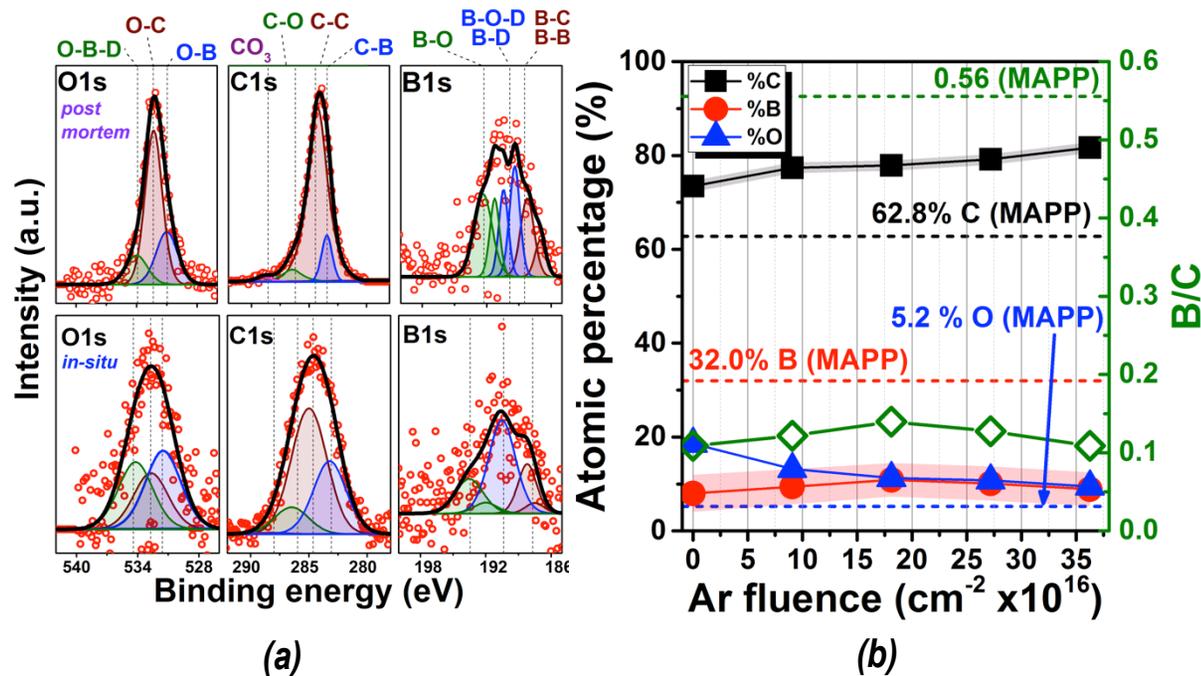


Same scale both



- 28 GHz launched in overdense plasma (a).
- Increase in T_e is observed on-axis about 0.5 m in front of target (b).
- Electron pressure is increased by a factor of ~ 1.6 (c).
- Neutral pressure is kept low during electron heating (d).
- IR images show increased heating at the target both on-axis and at the edges (e, f).

Post-mortem analysis of boronized ATJ graphite samples & comparison with *in-situ* MAPP data



a) XPS spectra comparison between post-mortem and *in-situ* measurements. The post-mortem data was collected with a sample boronized in NSTX-U. The *in-situ* data were collected with MAPP, (b). Atomic concentrations obtained with and XPS depth profile of the same sample measured in panel (a) upper. The dashed lines show the average of the concentrations obtained with MAPP during the campaign.

F. Bedoya, H. Schamis, et al. "Study of D retention and impurity emission properties of oxidized B4C coatings under deuterium irradiation in NSTX-U." Accepted to 27th IEEE Symposium On Fusion Engineering. 4 – 8 June 2017, Shanghai, China

Scientific Achievement

This work leverages on the first *in-situ* PFC data collected in NSTX-U to compare boronization methodologies (full vs. mini) using complementary *post-mortem* analysis in the laboratory. These results can be used as guidance for future conditioning in NSTX-U

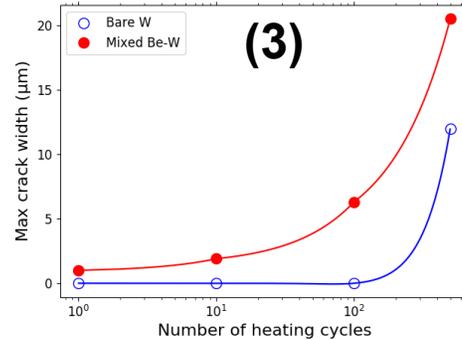
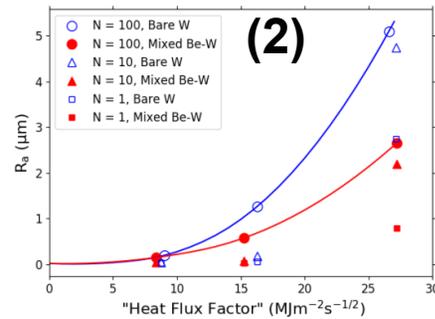
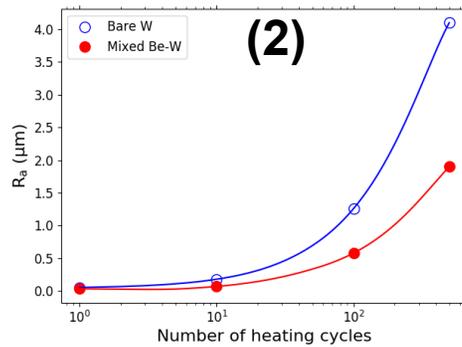
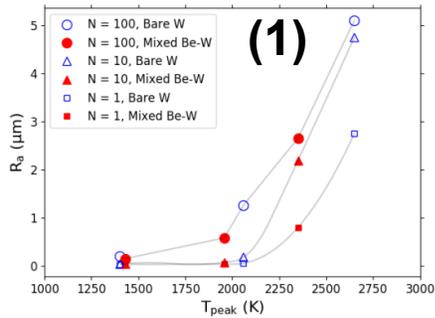
Significance and Impact

In this work we measured the impact that different boronization parameters e.g. time and amount of d-TMB have on the chemistry of deposited coatings.

Research Details

- In-situ* XPS data with MAPP diagnostic and *post-mortem* analysis shows how the concentration of B in the films depends on the total volume of d-TMB used. The *in-situ* data was taken after a full boronization whereas the *post-mortem* analysis was taken after a 1/3 d-TMB, as a consequence the B% decreased 20% and the B/C ~30%.

Repetitive Transient Heating Causes Increased Cracking of Be-W Alloy Compared to W

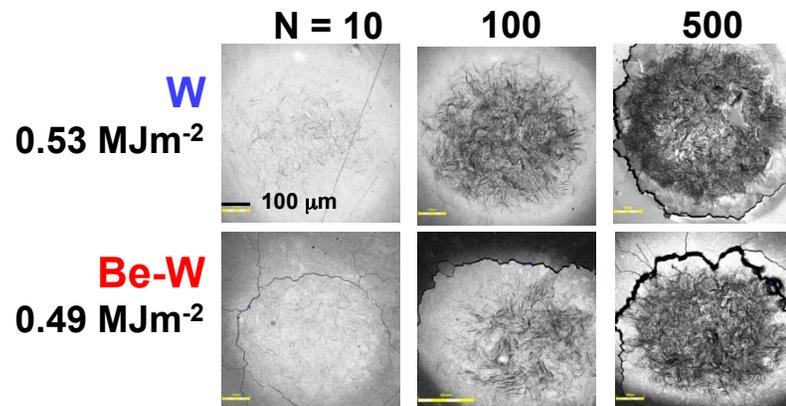


- **Be-W** alloy created in PISCES-B, and pulsed laser heating used to simulate ELMs with ITER ELM-like pulse shape
- (1) Transient-heat-induced surface roughness (R_a) depends on peak surface temperature (see J.H. Yu, Nucl. Fus., 55(2015)093027) for both **Be-W** and **W**
- (2) With same absorbed energy density, R_a and T_{peak} are lower for **Be-W** compared to bare **W**, due to differences in thermomechanical properties
- (3) Even with lower R_a , **Be-W** has higher susceptibility to transient-heat-induced cracking than **W**

Implications:

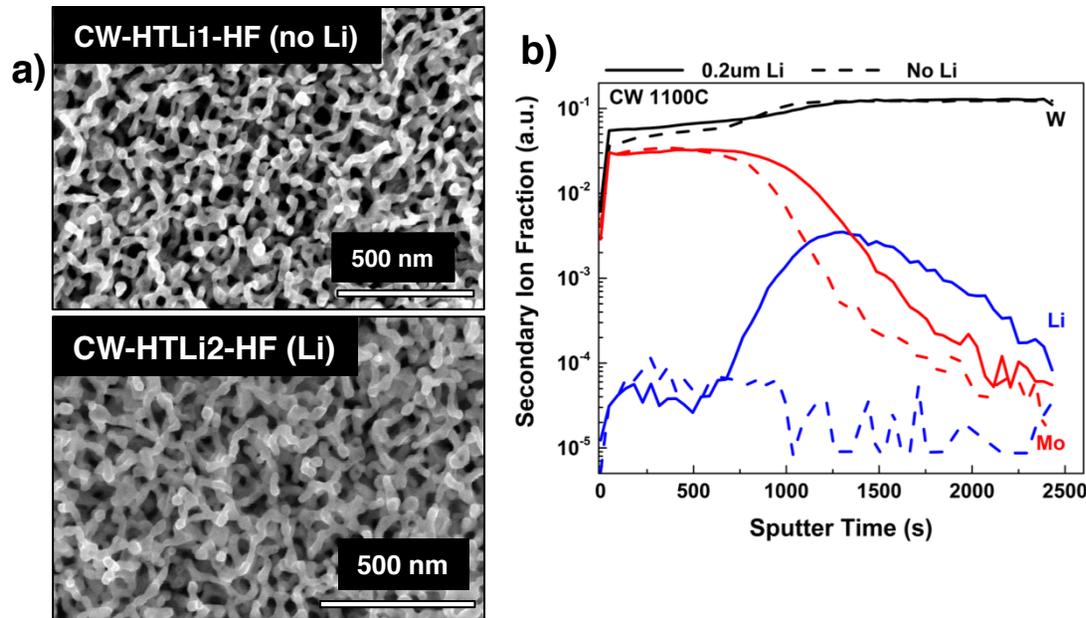
Conventional wisdom that roughening is a precursor to crack formation may not be valid for all materials. Data on physical properties of Be-W alloys is needed.

To be presented: J. H. Yu, Plasma Facing Materials Conference, Dusseldorf Germany, May 2017.



Elucidating low-Z thin film dynamics under high-fluence plasma exposure on nano-structured W

Coarse Grained W @ ~ 1373 K, Fluence $\sim 4.0E26$ m $^{-2}$



a) SEM micrographs of coarse-grained W, with and without a Li thin film deposited prior to exposure, showing formation of fuzz for both cases, b) Secondary Ion Mass Spectrometry depth profile of the same samples showing a trace of Li persisting on the surface.

- Irradiations were carried out in collaboration with T. Morgan at the Dutch Institute for Fundamental Energy Research.
- SIMS and SEM was carried out in part in the Frederick Seitz Materials Research Laboratory Central Research Facilities, University of Illinois.

Scientific Achievement

These results indicate that nano-structured fuzz still forms with Li present as a thin film and that the Li may not be removed from the surface.

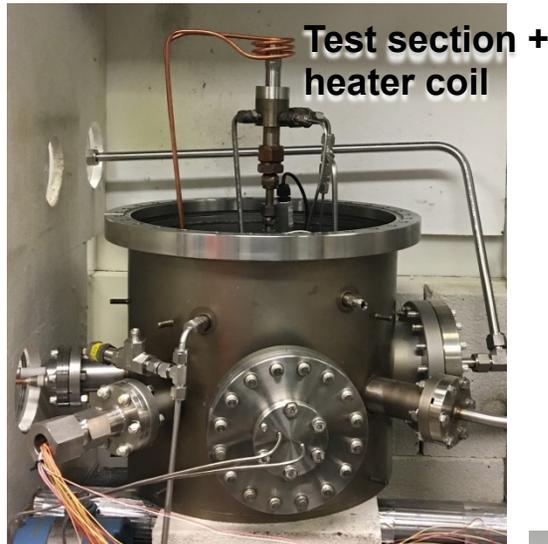
Significance and Impact

With the formation of fuzz in spite of the Li, indicates that fuzz would still form if Li coatings were used on W PFCs subjected to a He discharge in ITER. The reliance of the Li on the surface could be beneficial to prolong the fuel pumping capability of Li

Research Details

- Exposures of coarse-grained W with and without a Li thin film to He plasma at DIFFER at 1373 K at fluxes of 10^{24} m $^{-2}$ s $^{-1}$.
- Secondary Ion Mass Spectrometry (SIMS) depth profiling using Cs ions at the sputtering species and Au as the analysis beam show Li persisting under surface of tendrils.

Thermal-Hydraulics Experiments on He-Cooled Solid Divertors



Test section +
heater coil

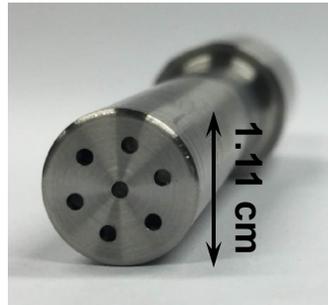
Vacuum chamber
(bottom section)

Application

Helium-cooled solid divertors leading candidate for solving power and particle exhaust issues in long-pulse fusion magnetic fusion devices.



Outer WL10
cartridge



Inner cartridge:
flat surface +
7 jets

Engineering Achievement

Simulations suggest that the complex He-cooled modular (“finger”) divertor with multiple jets (HEMJ) design can be simplified with 6.5% higher heat transfer coefficient, 4.8% lower max. stress on cooled surface (vs. HEMJ)

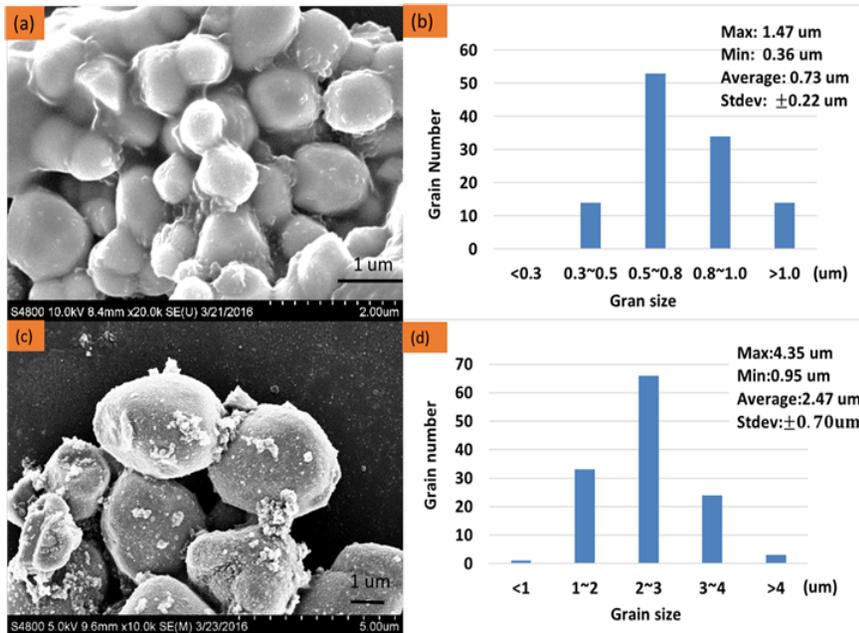
Significance and Impact

A simpler, more robust He finger divertor design should improve reliability and reduce cost

Research Details + Schedule

- Upgrading current Georgia Tech He loop to:
 - Enclose test section in vacuum chamber to minimize W oxidation and increase He inlet temperatures
 - Directly measure He mass flow rate through test section
- Experimental validation of simulations: test section with flat cooled surface and 7 jets (vs. curved surface and array of 25 jets for HEMJ) fabricated in stainless + WL10
- Start experiments on simplified finger design: April 2017
- HEMJ experiments to resolve discrepancies at higher He inlet temperatures (300-400 °C): Summer 2017
- Start building “large” He loop with maximum mass flow rate 100 g/s (vs. 10 g/s in current loop) in Summer 2017

Demonstration of Direct LiT Electrolysis using an Immersion Cell at SRNL



Grain size reduction for Lithium Lanthanum Zirconate (LLZO) achieved by using a sol-gel method of synthesis as compared to a solid-state reaction method

B. Garcia-Diaz, J. A. Teprovich, H. R. Colon-Mercado

Scientific Achievement

- Direct LiT electrolysis has the opportunity to simplify tritium recovery from a liquid lithium cooling blanket
- Improvement of the conductivity and structural integrity of the solid lithium ion conducting materials is critical to creating a viable direct LiT electrolysis process.

Significance and Impact

A direct LiT electrolysis process can eliminate the need to use molten salts for LiT recovery and can eliminate the need for centrifugal separators used in the Maroni process for LiT recovery

Research Details

- A sol-gel method was developed for LLZO synthesis that enabled a reduction in grain size to between 0.5 and 0.8 microns as opposed to 2-3 microns for the solid state reaction pathway
- The ionic conductivity of the electrolyte is a function of a number of variables, including grain size. The reduction in the LLZO grain size should enable increased conductivity.

SNL Highlights on PSI, PFC & ITER R&D

Science based understanding of PSI

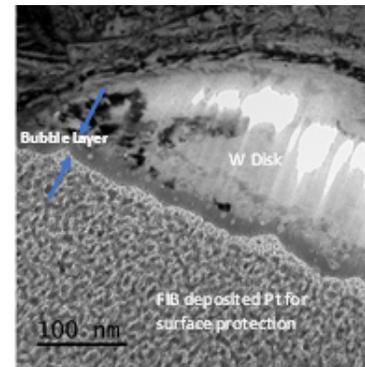
- Interactions of H/D/T and He with materials (*TPE & PISCES collaborations*)
 - Helium bubble layer in PISCES samples examined by ellipsometry
 - Preparation of DiMES experiments for H retention in UFG W

Plasma edge measurements

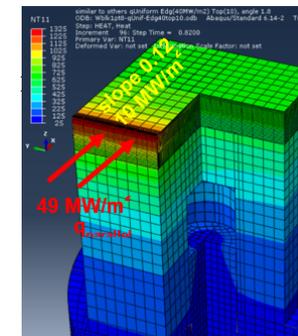
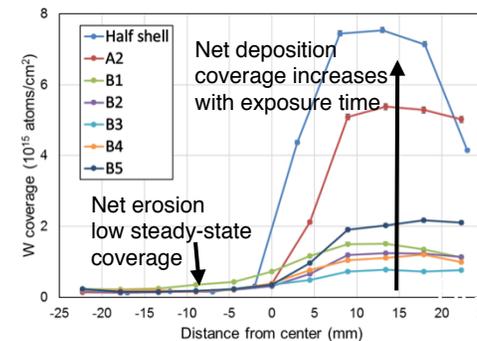
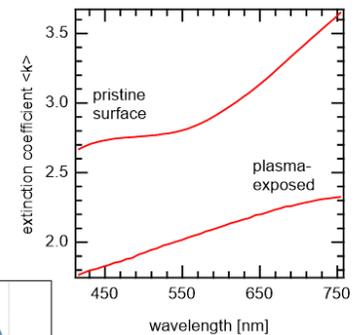
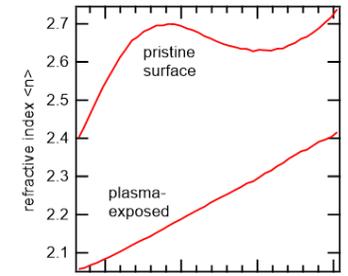
- Erosion/redeposition measurements (*DIII-D, NSTX-U, EAST collaborations*)
 - W migration during DIII-D metal ring campaign
- SAS divertor probes, embedded TCs, H-sensors
 - Probe array characterizing detachment in DIII-D SAS divertor found to depend on strike point location, density, and drifts

Science based-engineering

- PFC thermal models: DIII-D experiment on W blocks with protruding edges confirms ITER design assumptions when model accounted for pitch of block's surface.
- Novel materials and designs: Nygren, Garrison, "Potential for AM in Developing Fusion PFCs," submitted to ISFNT13 (2017)



30 nm Bubble Layer



STAR Research Highlights

Completed modification of HTO catalysis beds from Pt/Al₂O₃ to CuO in Tritium Gas Absorption Permeation (TGAP) system

- CuO beds minimize the uncertainty in low tritium partial pressure data

Recent tritium permeation results through KO RAFM (advanced reduced activation alloy: ARAA) at low-temperature (300°C) low-tritium partial pressure ($P_{T_2} < 10^{-6}$ Pa) under US-KO NFRI-UCLA-INL collaboration revealed:

- Similar tritium permeability to EU RAFM (EUROFER97)
- Lower tritium permeability at 300°C than JA RAFM (F82H)
- Dependence of material composition in tritium permeation behavior

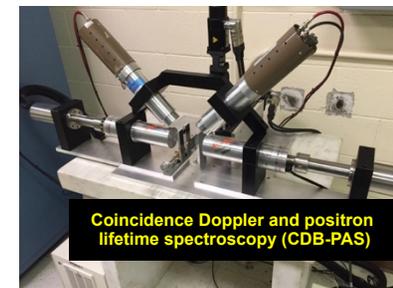
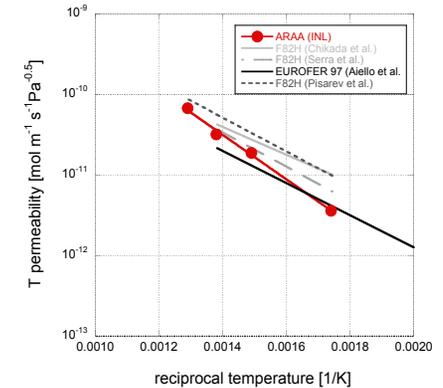
Higher Ta composition in ARAA and EUROFER97 than F82H

Completed relocation of coincidence Doppler and positron lifetime spectroscopy (CDB-PAS) system to the STAR facility.

- Add unique radiation-damage characterization capability at STAR for tritium-contaminated and low activation materials.
- Help advance tritium retention study in HFIR neutron-irradiated tungsten.

STAR Publication in FY17 Q2

C.N. Taylor, M. Shimada and B.J. Merrill, "Deuterium retention and blistering in tungsten foils", Nuclear Materials and Energy, <http://doi.org/10.1016/j.nme.2016.12.004>



Tritium Processing Development and R&D (LANL)

Application

Development and testing of tritium fuel cycle components and data-mining of TSTA historical documentation.

Scientific Achievement

Upgrades beginning on Hydrogen Processing Laboratory (HPL) test stand beginning. Participated in Liquid metal plasma facing component (LM-PFC) System Study.



HPL Test Stand



Upgrade



Significance and Impact

- Upgrades of HPL Test Stand will allow revitalization of tritium permeability and catalysis testing for fuel cycle development
- Integration of fuel cycle design into LM-PFC development will strengthen design options and applications.

Research Details

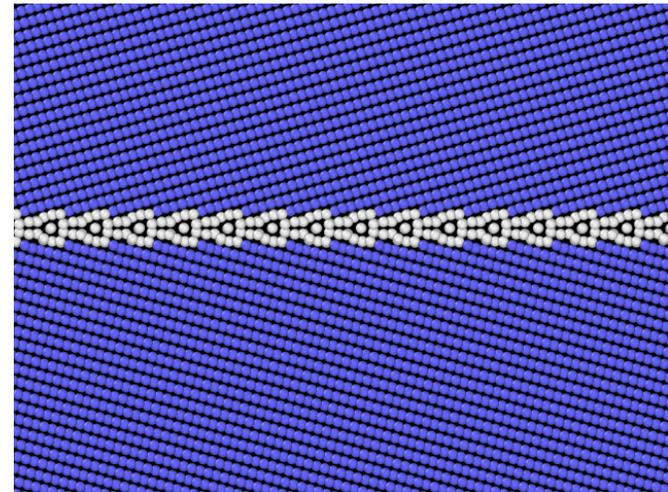
- New data acquisition hardware has been received. Work has been initiated on dismantling of outdated system, upgrades to wiring and controls and installation of new components. Design on uranium storage bed has been finalized and new heaters and supporting hardware are being purchased.
- Presented Tritium Fuel Cycle concepts at LM-PFC system study.
- Updated Export Control Requirements for Tritium Processing Design and R&D document based on 2016 updates to Export Control Classification Numbers (ECCN).

Hollis, W. Kirk, Maynard, S. and Niemi, K. M., Export Control Requirements for Tritium Processing Design and R&D. LA-UR-15-28493, 2017 update

Advanced materials modeling by LLNL finds new ground states of tungsten grain boundaries

- Recrystallization limits the operating temperature for tungsten in divertor and first-wall applications in tokamaks.
- Molecular dynamics and multiscale modeling techniques in collaboration with UCLA (Marian et al) are used to develop a predictive model of recrystallization.
- Predicted, for the first time, the phase transformations in tungsten grain boundaries (GB) at high temperature. Calculations of GB properties that affect recrystallization need to start with the correct structure.
- In Q2, used evolutionary algorithms to find additional novel GB structures, e.g. the $\Sigma 27$ boundary shown.

Unconventional Grain Boundary Structure for Tungsten:
[110] symmetrical tilt $\Sigma 27$



Using evolutionary grand-canonical search methods we have found new ground states of tungsten grain boundaries not predicted previously due to the limitations of common methods for grain boundary construction. We have also found novel high-temperature GB structures for tungsten.

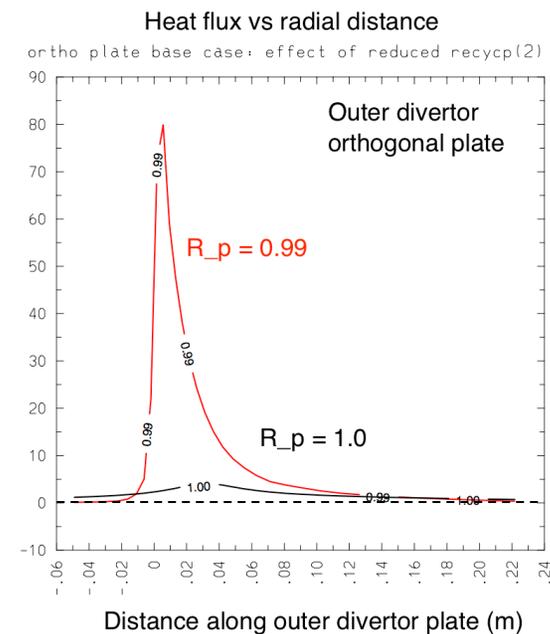
Robert E. Rudd and Tim Frolov



LLNL Group Modeling and Comparing Edge Plasmas for Solid & Liquid PFCs

- Identified molecular heating and energy flux to PFCs as being significant; refining model to provide full energy accounting.
- Extended data for UEDGE plasma and neutral fluxes for highly radiative FNSF divertor to begin liquid metal assessment.
- Related to liquids that pump hydrogen, simulated modest reduction of divertor-plate particle recycling from $R_p=1.$ to 0.99; peak heat-flux increased strongly.
- Showed that strong gas puffing can restore previous low heat-flux conditions when $R_p=0.99.$

Modest reduction in plate recycling can cause attached plasma with high heat-flux



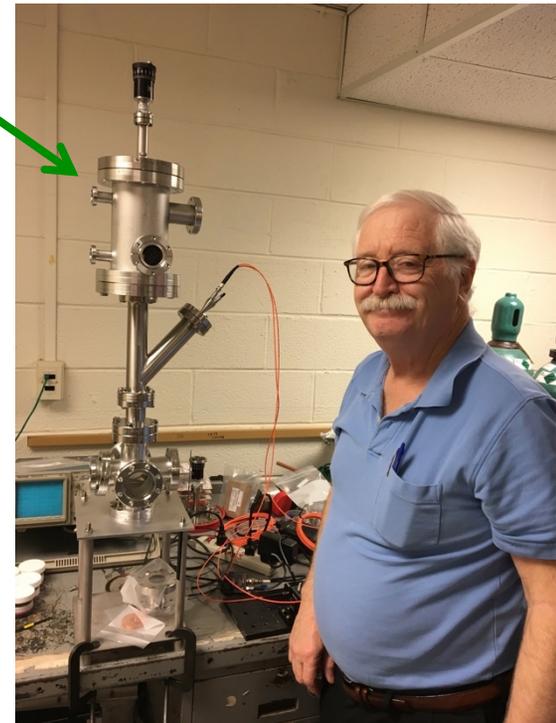
Strong gas puffing can restore low heat-flux conditions

T.D. Rognlien, M.E. Rensink, *Fusion Eng. Design*, submitted.



New equipment developed for use on US-PRC PMI collaboration on EAST

- New four chamber granule dropper developed, tested, shipped to EAST
 - Should be available for May-June 2017 campaign
 - New four chamber powder dropper also developed and tested
- Flowing liquid Li limiter development continued, targeting Dec. 2017 campaign
 - Identified robust cartridge heaters for us in FLiLi (UI-UC collaboration)
- Continued analysis of Dec. 2016 experiments for SOFE 2017 papers, and new experiments proposed for 2017



VLT Members Contributed to ANS Grand Challenges

Overview

The American Nuclear Society is in a process to identify, accumulate, analyze, vet, select, release and promote a set of technical Nuclear Grand Challenges that need to be addressed by 2030. As a part of this process, the ANS Fusion Energy Division (FED) has identified seven Grand Challenges for Fusion.

Top Grand Challenges for Fusion

1. Qualification of advanced materials that can withstand extreme nuclear fusion and fission environments (high temperature, radiation damage and transmutation, helium and hydrogen surface and bulk effects, and compatibility with advanced coolants).
2. Safely and efficiently fuel, exhaust, breed, confine, extract, and separate tritium in unprecedented quantities.
3. Successfully demonstrate significant energy gain in a long pulse or steady-state burning plasma.
4. Development of an experimentally validated integrated predictive simulation capability that will reduce risk in the design and operation of fusion energy systems.
5. Development of an appropriate safety and licensing process for future nuclear fusion facilities, with related criteria, including the qualification of materials and safety-important systems.
6. Construct and operate a high flux, high-energy (10 to 15 MeV) neutron source for research in fusion, fission, transmutation, and radio-isotope production applications.
7. Demonstration of an effective plasma exhaust system that can operate under nuclear conditions and maintain performance for a lifetime that avoids frequent replacement.

Next Steps

- The top three Grand Challenges for Fusion have been submitted to ANS National by the FED Chair Arnold Lumsdaine.
- The top 6-10 Nuclear Grand Challenges submitted from across the Society will be announced at the next ANS National Meeting on June 12 in San Francisco, CA.



Honors & Awards

Robert Franklin Mehl 2017 AWARD

The Minerals, Metals and Materials Society

Dr. Steven J. Zinkle

UT-ORNL Governor's Chair for Nuclear Materials

For innovative research on microstructure/
property relationships in irradiated
materials enabling improved
understanding of performance limits and
design strategies for high-performance
radiation-resistant materials.



TMS

ORNL Staff & Post Docs Attend 9th ITER International School - Physics of Disruptions & Control

- **ITER hosts an annual international school for early career researchers to learn about key issues in fusion science**
 - The 2017 topic was disruptions, a key area of interest for ORNL
- **Three ORNL staff attended the school in Aix-en-Provence, France, Mar 20-24, 2017**
 - Jeff Herfindal and Trey Gebhart are Postdocs in the Experimental Plasma Physics and Plasma Technology & Applications groups, respectively
- **Daisuke Shiraki, early carrier staff, gave a lecture on Disruptions in DIII-D**
 - Daisuke is the first former ITER international school student to follow on as a lecturer

ITER site outside Cadarache, France



D. Shiraki, J. Herfindal, T. Gebhart

U.S. ITER/ORNL has responsibility for the ITER disruption mitigation system