RUTGERS
THE STATE UNIVERSITY
OF NEW JERSEY

Nanostructured Tungsten to Resist Blistering in Thermonuclear Reactors

Stephen Tse & Bernard Kear
Mechanical & Aerospace Engineering
Materials Science and Engineering

3 June 2009

Outline

- Statement of Problem
- Proposed Solution
- Technical Objectives
- Method

Statement of Problem

- Plasma-facing components (PFCs) experience intense neutron irradiation and very high surface heat flux
- In fusion reactors, long-term tritium retention is a critical issue (e.g. co-deposition with eroded first-wall material)
- Carbon-based materials can lead to formation of prohibitively high tritium inventories

➡ New materials and composites are needed for PFCs
  - Improved strength
  - Fracture toughness
  - Joining
  - Resistance to blistering due to interactions with retained helium and isotopes of hydrogen

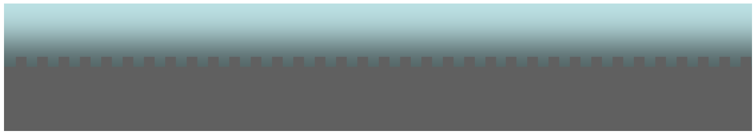
Tungsten

- Present ITER design is based on using tungsten, beryllium, and carbon for PFCs
- W is a promising alternative to low-Z materials such as C and Be, due to its high sputtering threshold energy (201 eV for deuterium impact, 136 eV for tritium impact) and its low sputtering yield
- ASDEX Upgrade has replaced all carbon fiber composite structures by tungsten-coated ones

➡ Tungsten plasma concentration (to avoid excessive heat losses) and tungsten erosion & migration processes are the main criteria to evaluate W as a first wall material

Proposed Solution: Nanostructured W

- *Nanostructured tungsten* alloys for PFCs
  - High grain-boundary diffusivity paths enable helium and hydrogen release
  - Improvement in strength, fracture toughness, and joining of plasma-facing materials
- *Functionally-graded* nanostructured coating on RAFM steel
  - Improves bonding (resistant to neutron radiation)
  - High thermal fatigue resistance
  - Prevents brittle intermetallic phase formation and coating debonding



Technical Objectives

- Synthesize W nanopowders using an inductively-coupled plasma (ICP) method
  - Rutgers Lab, Picatinny Arsenal
- Consolidate W nanopowders to form fully dense nanocrystalline samples
  - DMI, Picatinny
  - 1st time: high-pressure consolidation
- Produce a plasma-resistant tough crystalline W-Re alloy with high grain-boundary diffusivity paths
- Develop a method for joining tungsten alloys to RAFM steel, exhibiting resistance to thermal fatigue and neutron radiation
- Other
  - Dispersion of particles (e.g. WB_x) to prevent grain coarsening, to act as crack stoppers
  - Carbon nanofibers in a metal matrix

Method

ICP Synthesis (Rutgers: science base)

Synthesis Parameters

- RF power
- Gas (Ar, H_2, N_2, CH_4)
- Ambient pressure & gas
- Mass flow rates
- Precursor loading
- Substrate temperature
- Substrate voltage bias
- Substrate distance

Optimize Process

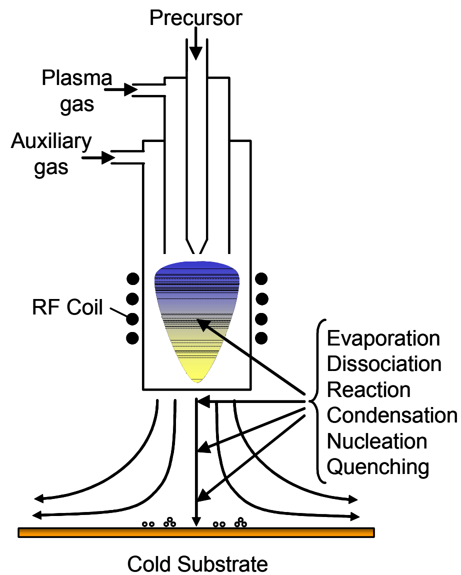
Predict & Guide Experiments

Validation

In-Situ Characterization

Gas-Phase diagnostics
- Temperature (SRS, FRS, OES. LIF)
- Chemical species (SRS, LIF, OES)
- Flow field velocity (PIV)

Particle diagnostics
- Composition (LIBS)
- Crystallinity (Raman)
- Size/Distribution (LII)



Computational Modeling

Gas-Phase phase
- Temperature
- Chemical species
- Flow field velocity

Particle growth & transport
- Sectional Model (precursor decomposition, nucleation, surface growth, coagulation, coalescence)
- Aerosol dynamics

Correlation

Correlation

Ex-Situ Powder Characterization

- Phase & crystallinity (XRD)
- Morphologies & primary particle size (TEM)
- Aggregate particle size (DLS)
- Powder surface area (BET)
- Particle size distribution (nano-SMPS)
- Precursor conversion (TGA)

ICP Synthesis (Picatinny: scale-up)

Consolidation of Nano-W

- Design reaction cell for high-pressure sintering of W nanopowder
  - Diamond Materials Inc. (DMI)
  - Compressed to full density under high pressure at ambient temperature to form a tough preform, which can be machined and further treated by roling, forming, forging, extrusion, etc.
- Spark Plasma Sintering (SPS)
  - DMI, Picatinny
  - High pressure cell, designed by DMI, can be incorporated directly into SPS unit at Picatinny Arsenal, enabling "pressure-assisted SPS"
- Determine parameters for hot pressing
  - Diamond Materials Inc. (DMI)

Joining Nano-W to RAFM Steel

- Nanopowders of W and Fe will be distributed between layers to establish a compositional or functionally-graded interface
- High pressure treatment and hot pressing for thermal fatigue resistance
- Determine parameters to minimize/prevent the formation of brittle intermetallic phases
  - increase interface strength
  - prevent coating debonding
- Same method can be used for joining Be to RAFM steel
- Joining of tiles

Testing Samples

- Evaluate mechanical and thermal properties
  - DMI, Rutgers
- Neutron-irradiation testing
  - PPPL

Partnerships Envisioned

- Rutgers University (ONR, DOE)
- Diamond Materials Inc. (SBIR/STTR)
- Picatinny Arsenal (Army)
  - Manufacturing R&D Facility
- Princeton Plasma Physics Laboratory