Multiscale Bubble Evolution Model
for Plasma Facing Materials

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Abstract

A multi-scale model of helium bubbles nucleation, coalescence, and diffusion will be described in the following sections. The hopes of this study is to fully characterize material damages bubbling could cause in the nuclear fusion process, and aid us in designing materials that are more resistant to such environment.

1 Introduction

1.1 Fusion Reaction Defects

1. $D + T \rightarrow He + Neutron + Energy$
2. Temperature $\approx 10^8\,^\circ C \rightarrow$ ionize helium plasma
3. Toroidal (Tokamak) chamber contains the plasma via magnetic field
4. Helium plasma at significantly lower temperature reach the diverter (usually tungsten)
5. Surface and bulk defects on tungsten are created by the helium plasma

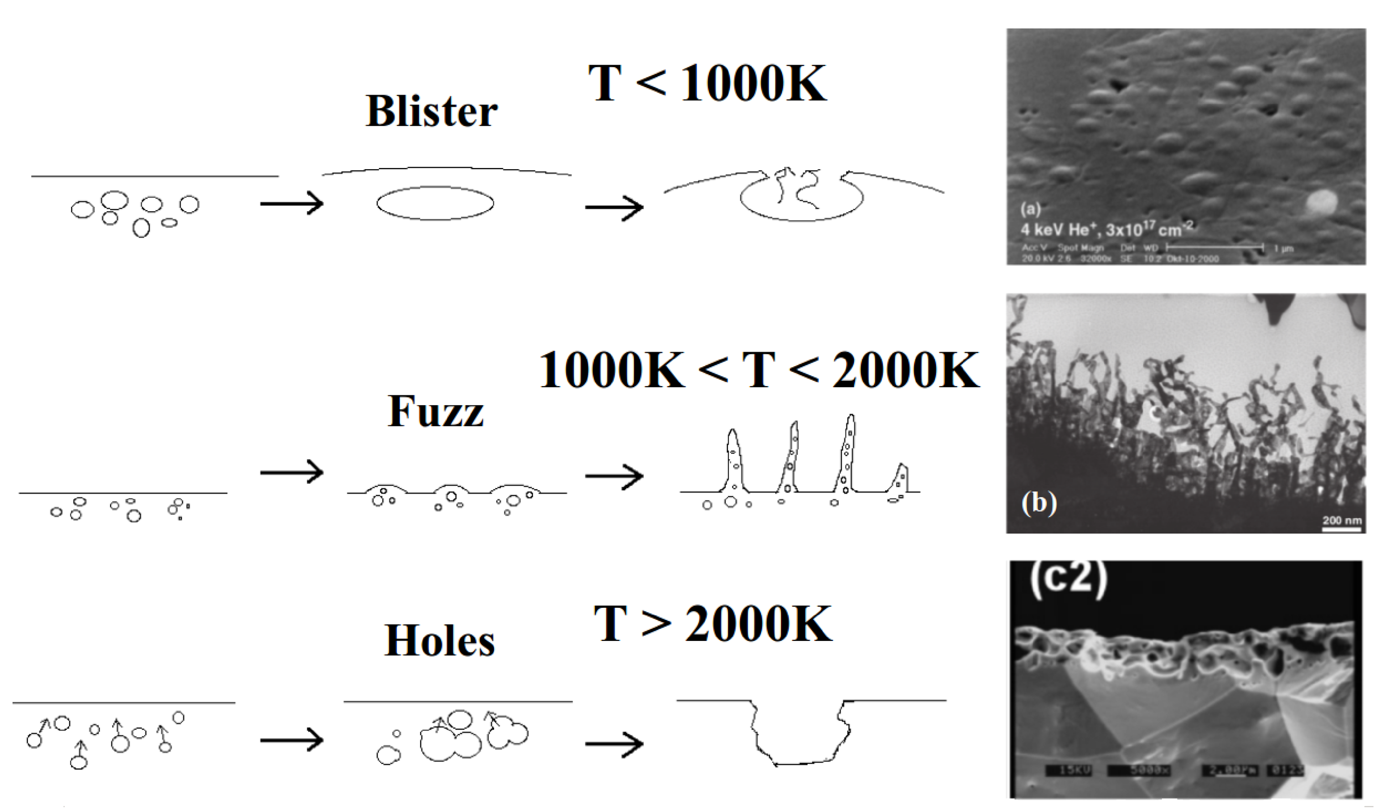

Figure 1: Helium bubble caused defects with temperature dependence [2], [1], & [3]

1.2 Main Objective

- Consolidate multi-scale helium-tungsten interaction models
- Fully characterize bubble diffusion and damage in metal
- Model and experiment on Micro-architecture metal surfaces

1.3 Research Impact

- Nuclear fusion is imperative to solving the energy crisis
- Fusion material defect and damage studies are an important factor in predicting their life-expectancy
- Compared to the tradition experimental studies, simulations are:
  - Safer
  - Lower Cost
- Simulation aid in the design of new materials/geometries

2 Model Summary

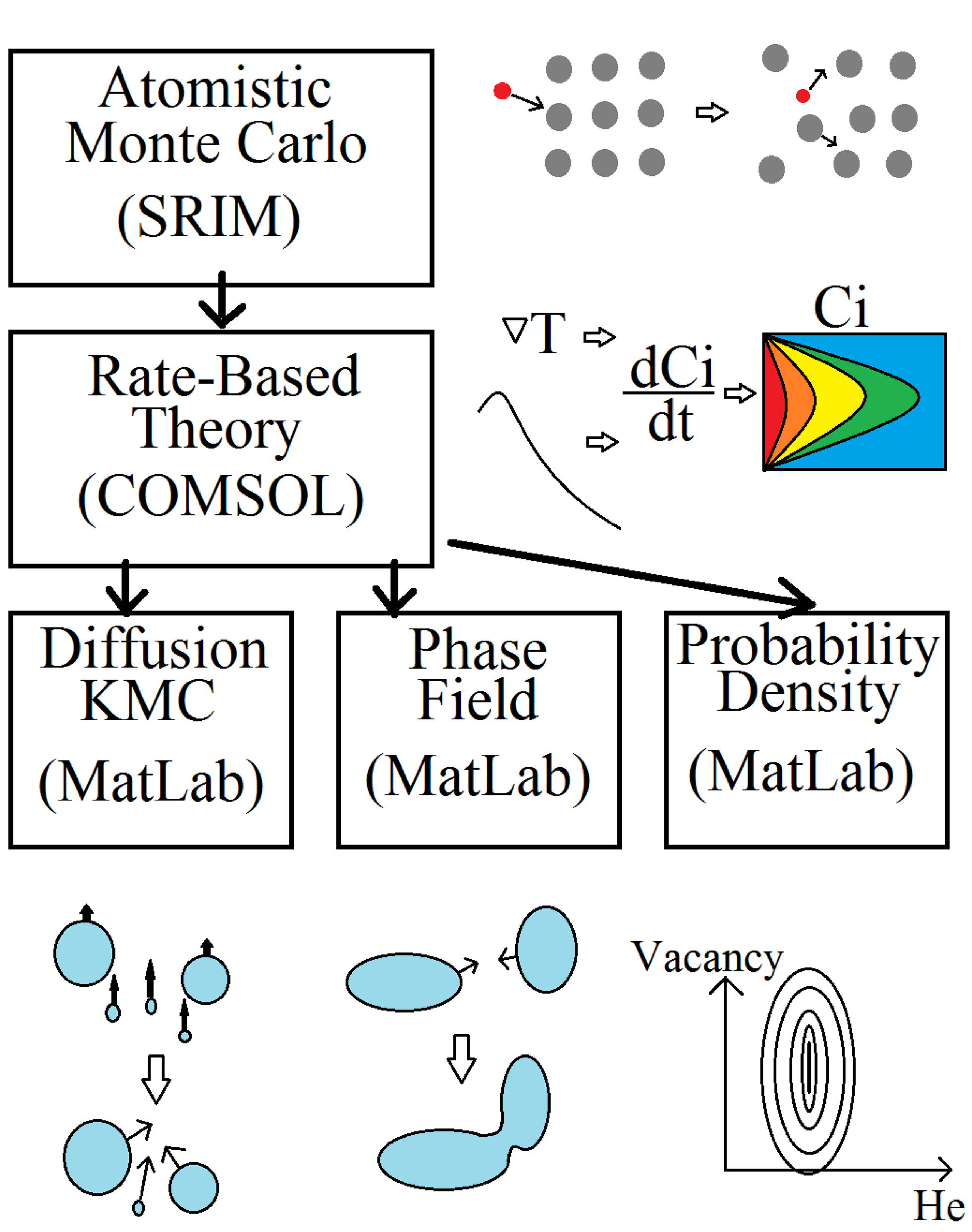

Figure 2: Overarching schematic representation of the multiscale multiphysics approach that will be employed to analyze helium bubble evolution in tungsten.

3 Results

3.1 Atomistic Interactions (SRIM)

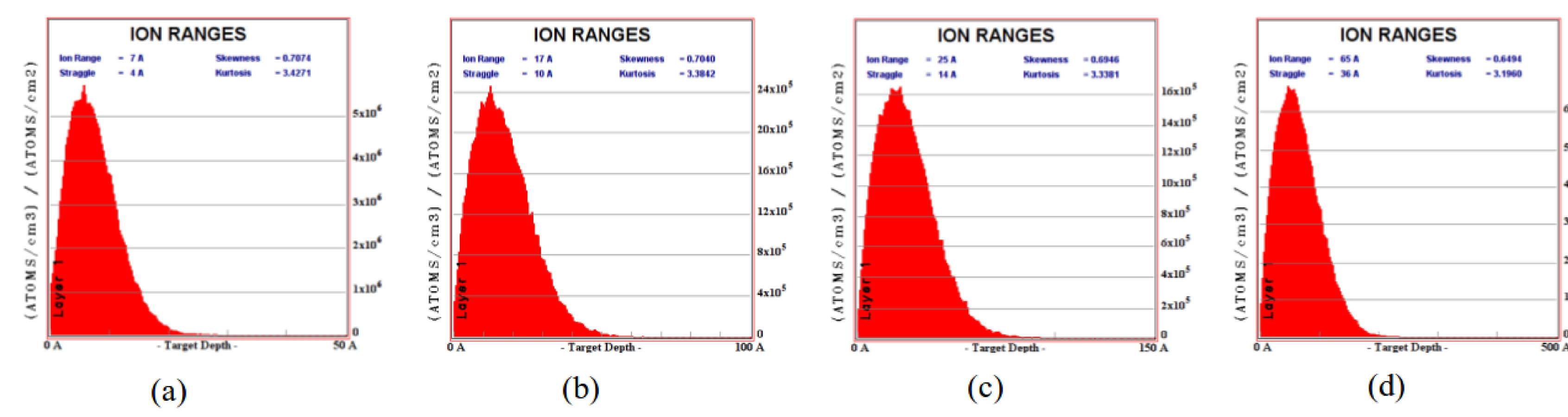

Figure 3: SRIM ion stopping range results for helium ion in tungsten lattice with ion energy of a) 20eV b) 100eV c) 200eV d) 1000eV

3.2 Rate-Based Theory (COMSOL)

This set of rate-based theory result is only for the SRIM output with helium ion energy at 20eV.

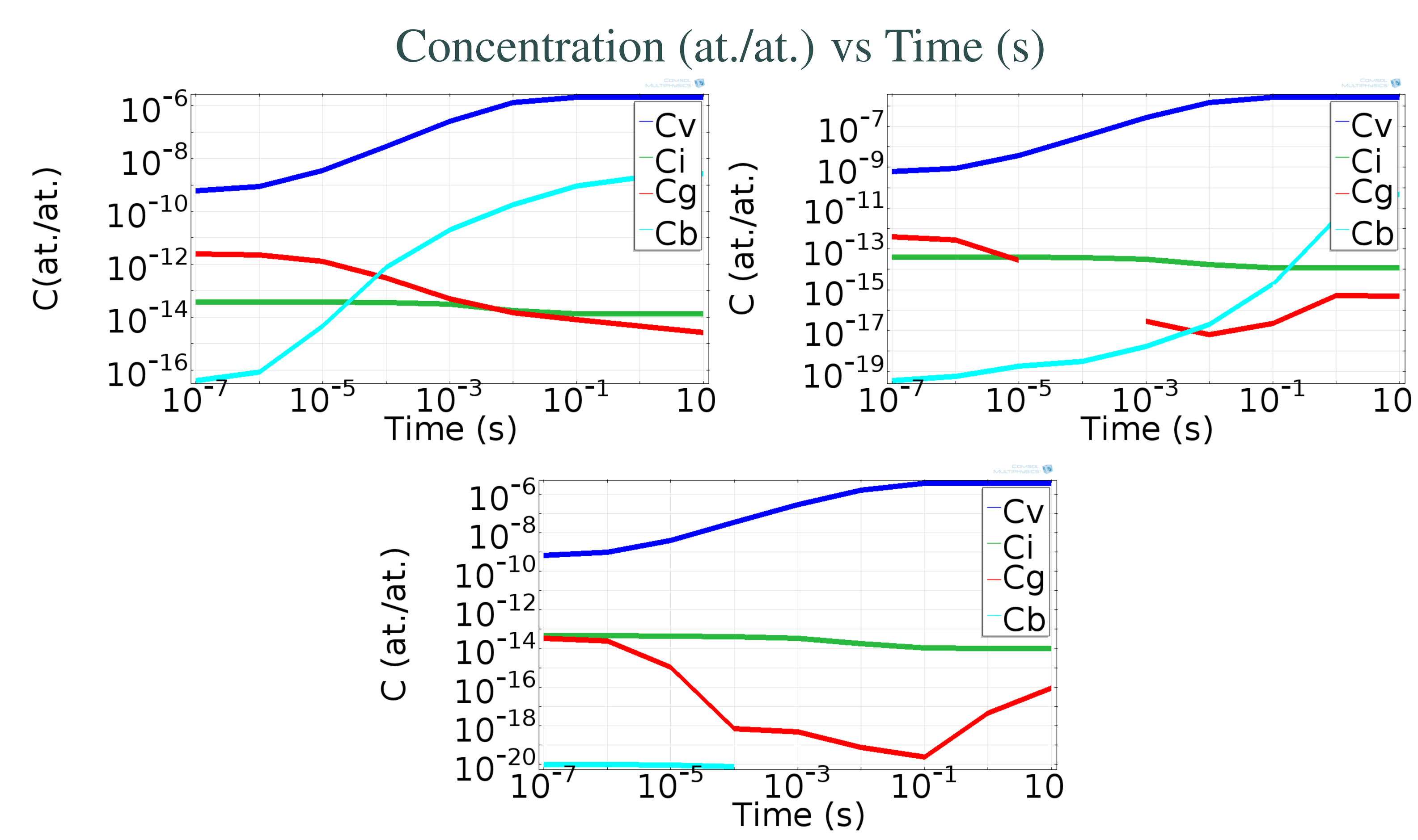

Figure 4: Left: Front of plate, Middle: Center of plate; Right: Back of plate.

3.3 Experimental Micro-Pillar

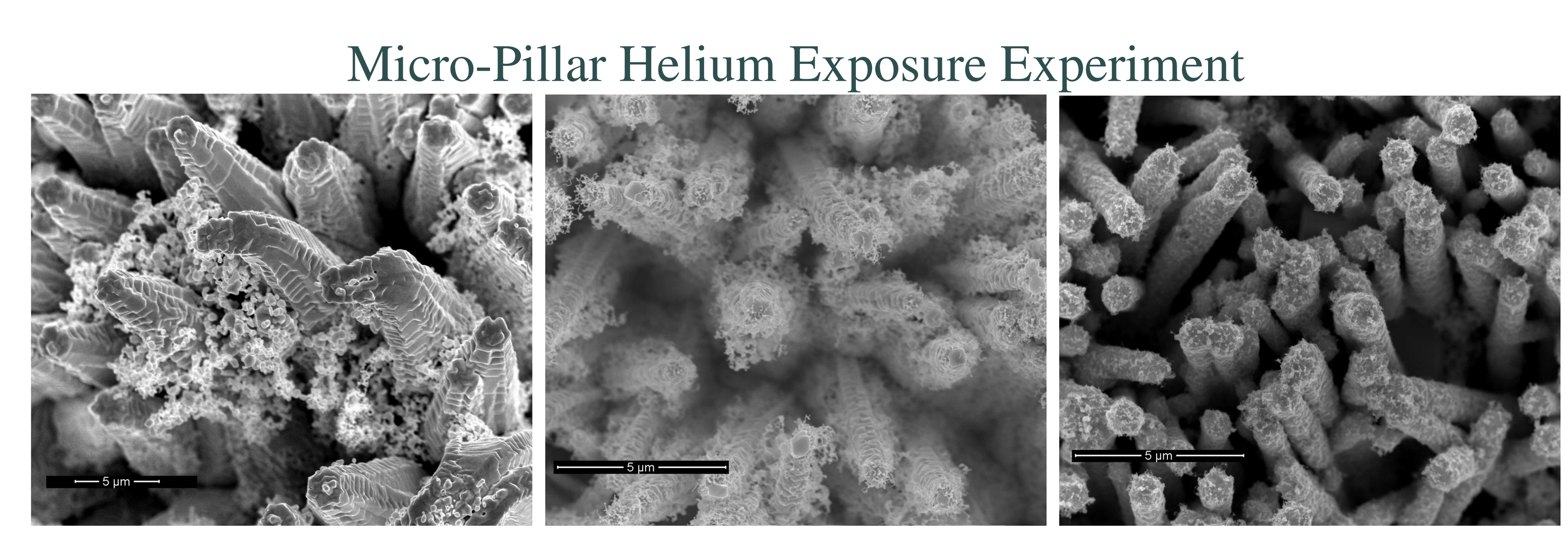

Figure 5: Left: 30eV He Ion; Middle: 60eV He Ion; Right 100eV He Ion exposure on W Micro-pillar $5 \sim 20\ \mu$m in diameter and 25μm in height

4 Conclusions

- Atomistic Monte Carlo transitions smoothly to Rate Theory PDE sets
- Rate Theory results in comparable defect concentrations to literature
- Micro-pillar experiment shows strong ion energy dependency on the amount of fuzz growth which can be modelled

5 Forthcoming Research

The concentration field from COMSOL can be applied to:

- KMC of bubble diffusion via forces acting on them and coalescence near the surface
- Phase field of bubble nucleation and coalescence in the bulk
- Probability density function of bubbles and defects via the size distribution overall

References

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[2] Wenmin Wang, J Roth, S Lindig, and CH Wu. Blister formation of tungsten due to ion bombardment. *Journal of Nuclear Materials*, 299(2):124–131, 2001.

[3] MY Ye, H Kanehara, S Fukuta, N Ohno, and S Takamura. Blister formation on tungsten surface under low energy and high flux hydrogen plasma irradiation in nagdis-i. *Journal of nuclear materials*, 313:72–76, 2003.

Acknowledgements

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