SAND2011-5809C

The Feasibility and Development of an *In situ* Ion Irradiation TEM at Sandia National Laboratories

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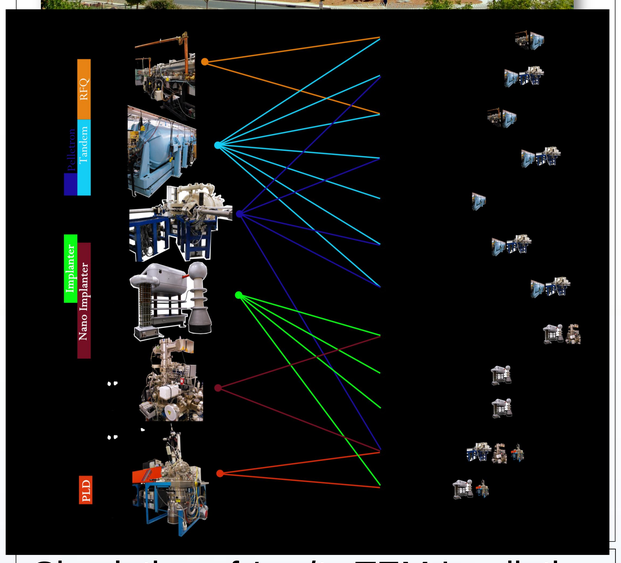
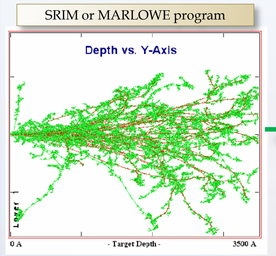
Sandia's Ion Beam Lab Capabilities



Simulation of *In situ* TEM Irradiation

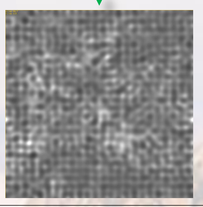
SRIM or MARLOWE program



Code developed to insert MARLOWE simulation into JEMS

Program developed to input Monte Carlo output into JEMS input format

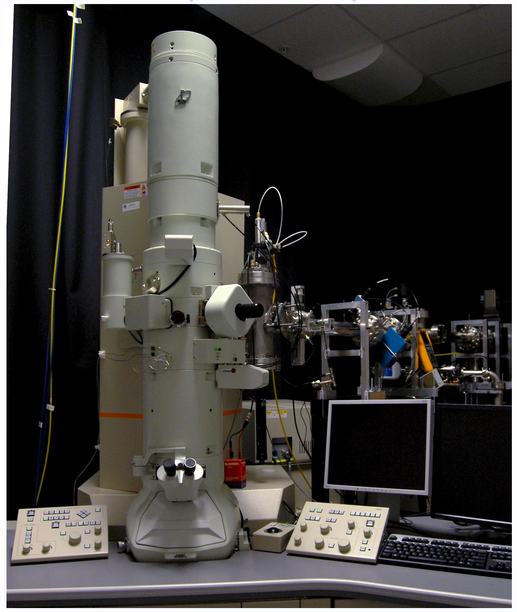
Java-based Electron Micrograph Simulation (JEMS)



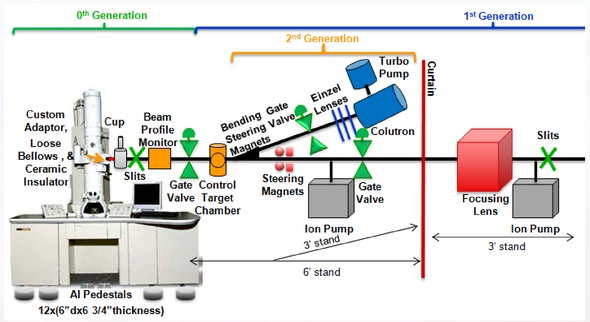
An algorithm was developed to run SRIM or MAROLOWE through a JEMS image simulation permitting a comparison to TEM experimental observations. A similar algorithm should be applicable to MD models

In situ Ion Irradiation TEM (I^3TEM)

I^3TEM triple beam development



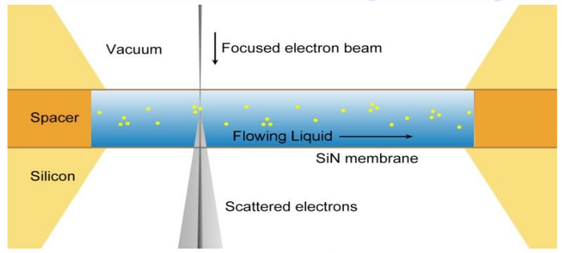
- This is only 1 of 11 world wide and only the 2ND in the US.
- The I^3TEM is designed for tomography and imaging of biological samples due to a high contrast polepiece and the single electron sensitive CCD camera.

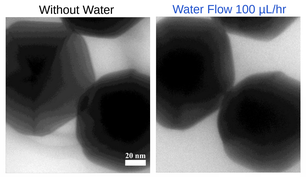


- A schematic of the I^3TEM beamline and its components
- Great care was taken in the development of the I^3TEM to permit vacuum, electrical, and mechanical isolation.
- The beamline is currently being developed to permit simultaneous concurrent implantation of protons, alpha particles, and heavy ions on the same location of a TEM specimen using a 6MV Tandem and a 10 kV Colutron
- The ion energy range is being developed to operate from 1 keV to 80 MeV.

In situ TEM Stages

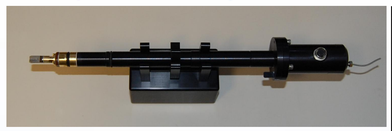
Fluid Cell with Microfluidic Mixing and Heating

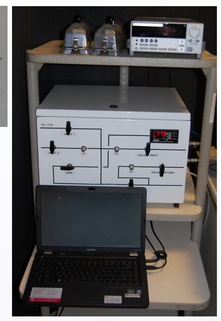




- A Protochips microfluidic stage permits the mixing of two microfluidic channels at elevated temperatures.
- This permits real time nanoscale observations of the interaction of materials in aqueous or other solutions.

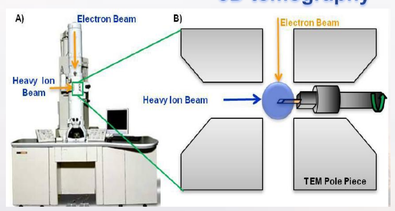
Vapor Cell with Up to 1 atm Pressure and Heating

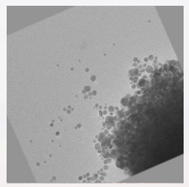


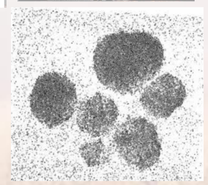


- Permits real time observation of the interaction that occurs at a solid – vapor interface at ambient temperature through 1200 ºC
- TEM images have been collected of samples as they were exposed to room air at standard temperature and pressure.

3D tomography



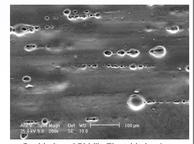




- Hummingbird simple tomography stage and IMOD software permits automated 3D reconstructions
- The combination of tomography and in situ capabilities permits 4D studies

Future Work

1. Observe corrosion at the nanometer scale to determine the mechanisms behind localized etching and pitting
2. Triple beam ion implantation of heavy ions, He, and deuterium to simulate the effects of displacement damage, swelling, and hydrogen embrittlement, as seen in cladding metals for nuclear reactors
3. Microstructural evolution of nanograined and nanolamellar structures exposed to ion irradiation
4. Electron and ion irradiation of scintillators to understand the evolution of radiation detectors exposed to various radiation sources
5. Single heavy ion implants into microelectronics to simulate the microstructural evolution seen in space environments
6. Study nucleation, growth, and motion of various nanoparticles
7. Study the mechanisms governing self-assembly and directed assembly



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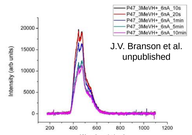
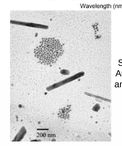
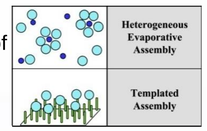


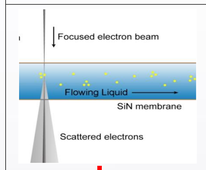
J.V. Branson et al. unpublished

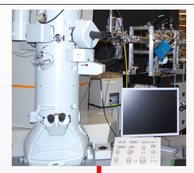


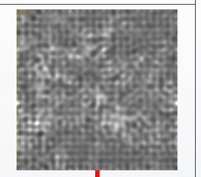
Self-assembled Au nanoparticles and Cu nanorods



Conclusions







Fundamental Understanding of the Mechanisms Governing Irradiation Damage in a Wide Range of Materials

The recent I^3TEM capabilities developed at the Ion Beam Lab should permit the **potential for** direct real time observation at the nanoscale of various systems ranging from biologically assembled nanoparticles through cladding materials for next generation nuclear reactors.

Acknowledgements

Dan Buller, James Scott, Janelle Branson, Melissa Dosanjh, Brad Yates, Stephen Foiles, and Mike Moran

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Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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