Sandia’s Ion Beam Laboratory

Ion Beam Analysis (IBA)

Radiation Effects Microscopy (REM)

Ion Beam Modification (IBM)

*In situ* Ion Irradiation Transmission Electron Microscopy (I³TEM)
Overview
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Ion Beam Analysis
- **The basic concept:** A charged particle interacts with a material and one of a variety of signals produced gives information on the local chemistry and structure.
- Each beam has associated benefits and limitations.

Radiation Effects Testing
- Space and other nuclear environments demand radiation hardness.
- Can simulate radiation damage from a single ion strike to up to 500 dpa.

Ion Beam Modification
- **The basic concept:** Alteration of the structure through ion beam interactions.
  - Implantation of dopants
  - Sputtering of material
  - Decomposition of gasses

In-situ Ion Irradiation Transmission Electron Microscopy
- **The basic concept:** Characterization of materials exposed to various types of particle bombardment in real-time, at the nanoscale.
- Current capabilities include:
  - Heating
  - Straining
  - Tomography

IBA, radiation effect testing, and ion beam modification are all widely used in research and industry.

http://www.pbeam.com
In Situ Transmission Electron Microscopy (I\textsuperscript{3}TEM)

Characterization of materials exposed to various types of particle bombardment in real time, at the nano scale

The IBL is one of only 11 facilities worldwide with this capability.
**In situ Ion Irradiation TEM (I³TEM)**

**Proposed Capabilities**

- 200 kV LaB₆ TEM
- Ion beams considered:
  - 1 MeV H⁺
  - 3 MeV He⁺, Si³⁺, Cu³⁺, Au³⁺, W³⁺
  - 14 MeV Si³⁺
  - 10 keV D²⁺
  - 10 keV He⁺
- All beams hit the same location
- Electron tomography
- Nanosecond time resolution (DTEM)
- Precession scanning (EBSD in TEM)
- **In situ** PL, CL, and IBIL
- **In situ** heating and cooling stages
- **In situ** electrical measurement stage
- **In situ** quantitative mechanical testing
- **In situ** vapor phase stage
- **In situ** liquid mixing stage

**We have completed the Tandem accelerator connection and Colutron accelerator connection.**

Many potential additions are being considered.
Current Status of the *In situ* TEM Beamline

I³TEM is operational, but also still in development.

- **Double tilt stage needs to tilt only 12°**
- **10 kV Colutron**
- **6 MV Tandem**
- **Bending Magnet to Mix Beams**
- **Vibration Isolations**
- **Pre-TEM Coupon Irradiation Chamber**
- **Faraday Cup and Viewing Screen**
- **Microfluidic Holder Beam Burn**

Beam burn from 14 MeV Si

Collaborators: D.L. Buller & J.A. Scott
Can We Gain Insight into the Corrosion Process through *In situ* TEM?

**Microfluidic Stage**
- Mixing of two or more channels
- Continuous observation of the reaction channel
- Chamber dimensions are controllable

**Cross-sectional schematic**

Pitting mechanisms during dilute flow of acetic acid over 99.95% nc-PLD Fe involves many grains. Large grains resulting from annealing appear more corrosion tolerant.
Other Fun Uses of Microfluidic Cell

**Protocell Drug Delivery**
S. Hoppe, E. Carnes, J. Brinker

Liposome encapsulated Silica destroyed by the electron beam

**BSA Crystallization**
S. Hoppe

Crystallization of excess Bovine Serum Albumen during flow

**Liposomes in Water**
S. Hoppe, D. Sasaki

Liposomes imaged in flowing aqueous channel

**La Structure Formation**
S. Hoppe, T. Nenoff

La Nanostructure form from LaCl$_3$ H$_2$O in wet cell due to beam effects
Radiation Tolerance is Needed in Advanced Scintillators for Non-proliferation Applications

**In situ** Ion Irradiation TEM (I^3TEM)

High-Z nanoparticles (CdWO₄) are promising, but are radiation sensitive

Tomography of Irradiated CdWO₄:
3 MeV Cu³⁺ at ~30 nA

Contributors: S.M. Hoppe, B.A. Hernandez-Sanchez, T. Boyle
In situ TEM Quantitative Mechanical Testing

Radiation effect on mechanical properties
- Direct correlation of dose and defect density with resulting change in strength and ductility
- Failure of Mo-wire after 3 MeV Cu irradiation

Contact and fatigue effect on structure
- Associate change in local hardness and fatigue with corresponding nanostructure
- Indent and Fatigue of nanocrystalline Cu film

Fundamentals of contact reliability
Can *In situ* TEM Address Hydrogen Storage Concerns in Extreme Environments?

**Vapor-Phase Heating TEM Stage**

- Compatible with a range of gases
- *In situ* resistive heating
- Continuous observation of the reaction channel
- Chamber dimensions are controllable
- Compatible with MS and other analytical tools

**Harmful effects may be mitigated in nanoporous Pd**

New *in situ* atmospheric heating experiments provide great insight into nanoporous Pd stability