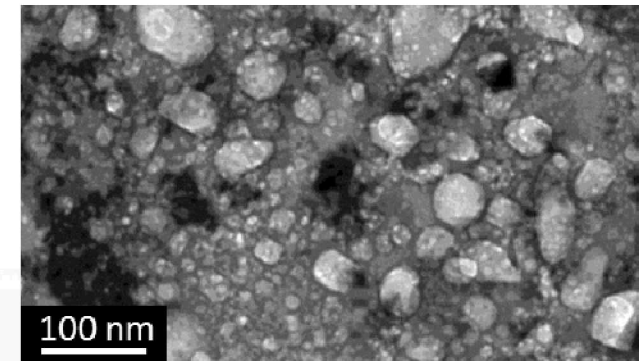
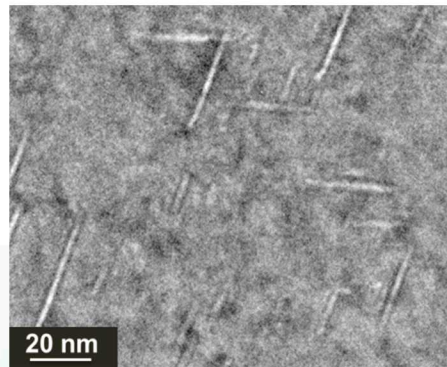
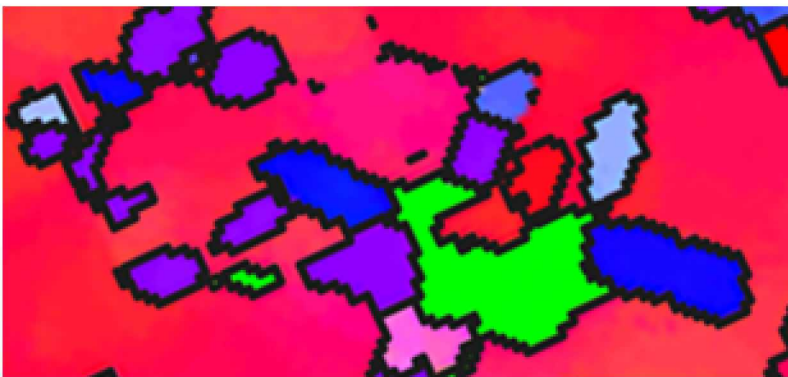


Proof of Concept for Tritium-based Accelerated Aging



Brittany Muntifering
Clark Snow, Khalid Hattar



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-AC04-04OR21400.

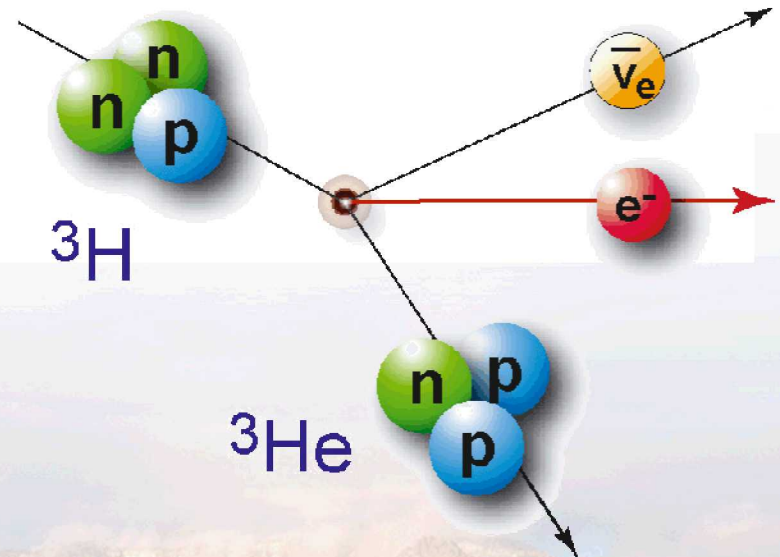
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. **Sandia National Laboratories**

Beta Decay of Tritium

- Radioactive decay through emitting an energetic electron



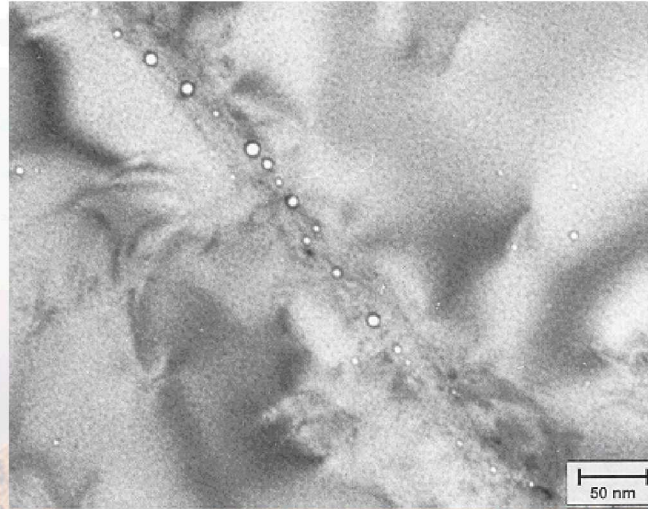
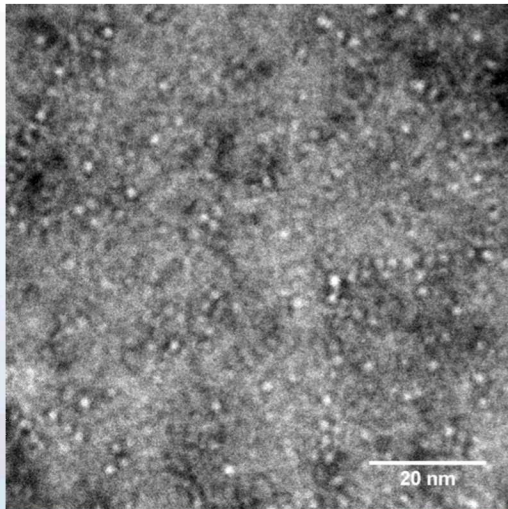
- 12.3 year half life
 - Tritium storage materials
 - Plasma facing materials in fusion reactors



Helium Effects on Materials

- Insoluble in most materials
- Forms high pressure nanoscale bubbles
- Detrimental Impact on Mechanical Properties
 - Embrittlement
 - Fatigue
 - Swelling

Helium bubbles cause materials to become prone to **unpredictable fracture and release of helium**



<http://energy.materials.ox.ac.uk/>

W. R. Kanne, Jr., M. R. Louthan, Jr., D. T. Rankin, and M. H. Tosten. Weld Repair of Irradiated Materials.

Goodhew, P. J., and Tyler S. K. "Helium Bubble Behaviour in B.c.c. Metals Below 0.65Tm."



Sandia National Laboratories

Limitations in Studying Helium Evolution

1. Time consuming

2. Expensive

3. Difficult

- 12.3 year half life of tritium
- Complexity of radiological TEM sample preparation
- Reactor-irradiated specimens are highly radioactive and post-irradiation testing must be carried out in hot cells

The lack of realistic, validated accelerated aging methods has slowed progress in understanding helium bubble evolution



Sandia's Concurrent *In situ* Ion Irradiation TEM Facility

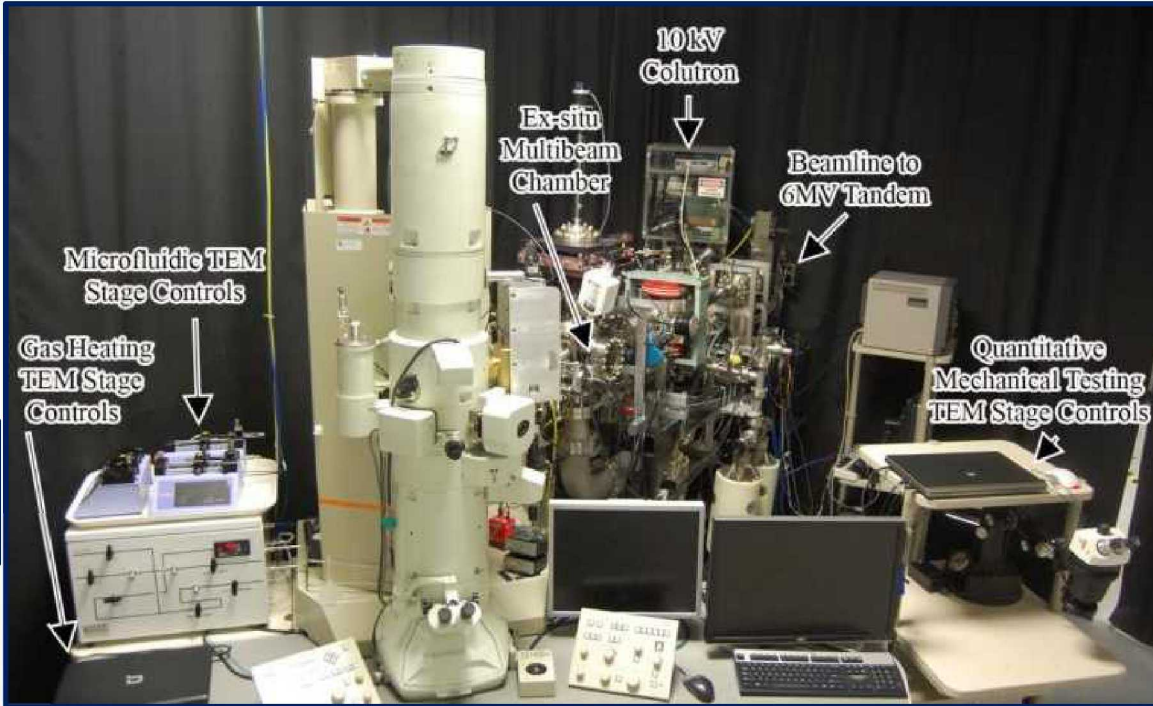
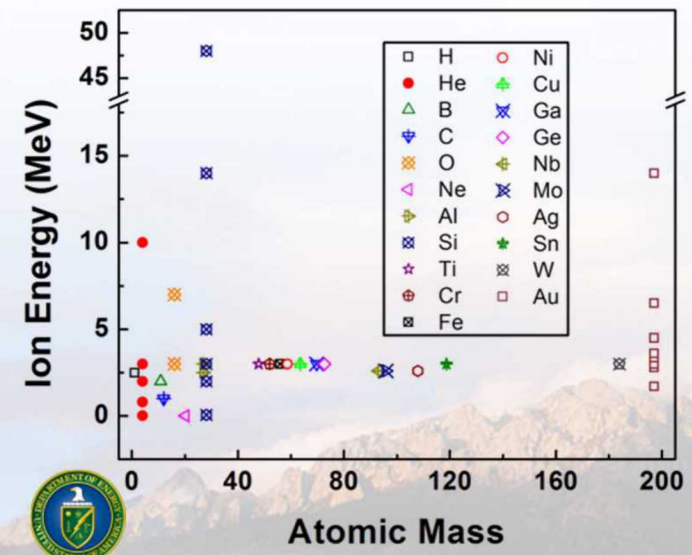


6 MV Tandem



10 kV Colutron

Heavy Ion Irradiation + Gaseous Implantation
 Control ratio of dpa and gas species implantation and characterize coupling effects



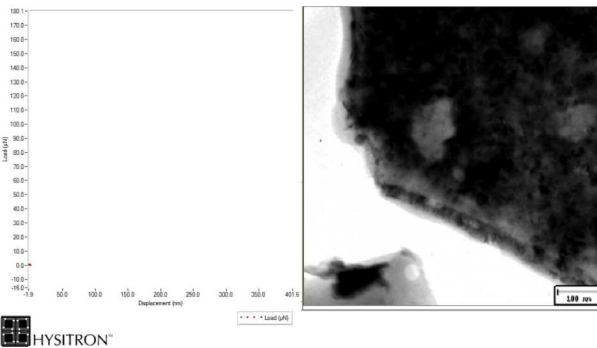
200 kV JEOL 2100 TEM

Direct real time observation of ion irradiation, ion implantation, or both with nanometer resolution



Radiation & Potential Synergistic In- Situ Capabilities

Mechanical Effects

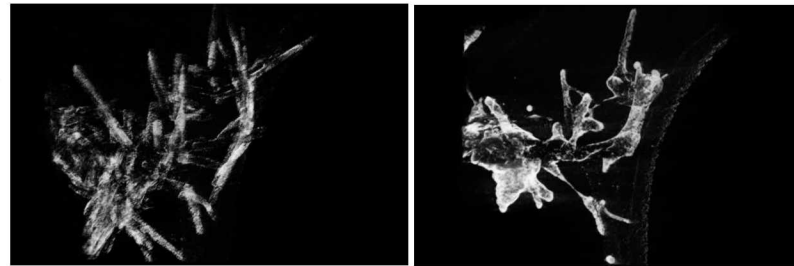


Hysitron PI95 TEM Picoindenter Gatan 654 Straining Holder

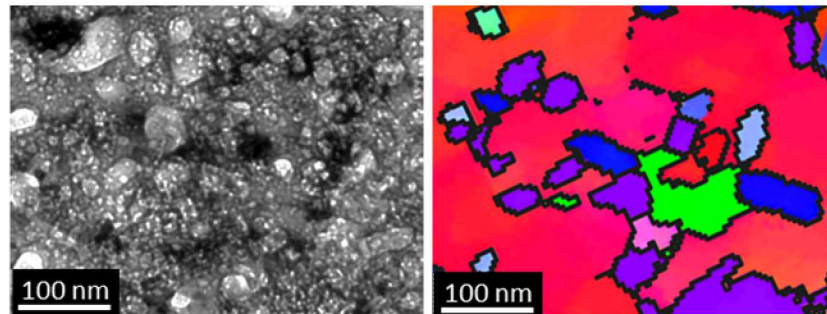
Allows for direct correlation of dose and defect density with resulting changes in strength, ductility, and defect mobility

Structural Effects

Hummingbird Tomography Stage
Gatan 925 Double Tilt Rotate
Morphology changes as a result of radiation damage



Nanomegas ASTAR
Grain structure changes as a result of radiation and implantation



Thermal Effects

Hummingbird Heating Stage
Coupling effects of temperature and irradiation on microstructural evolution up to 800°C



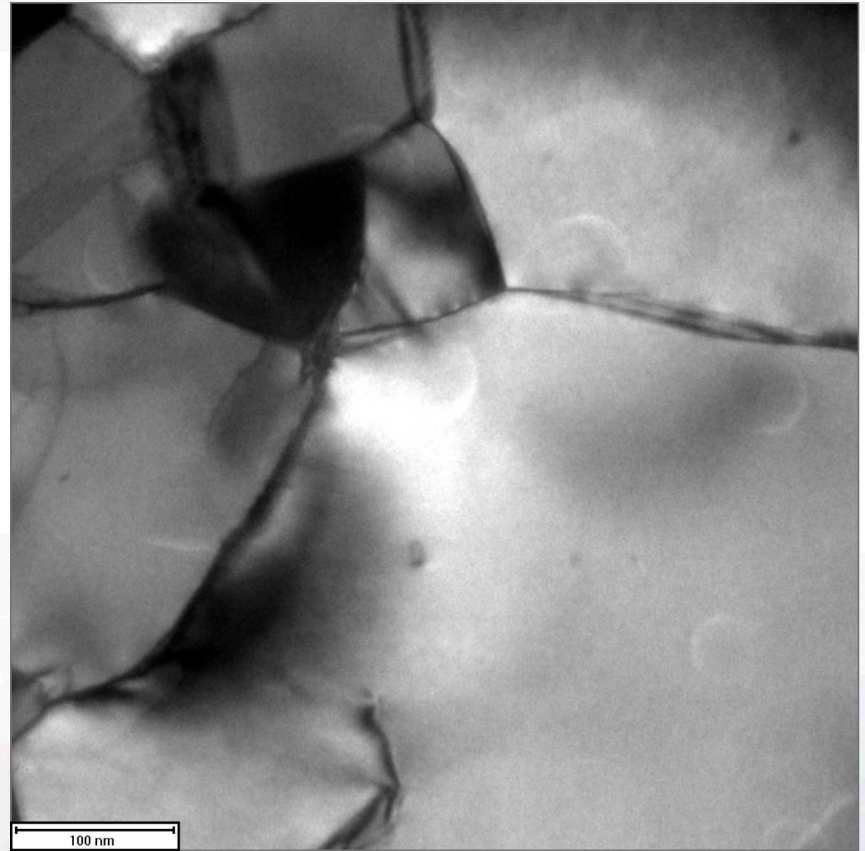
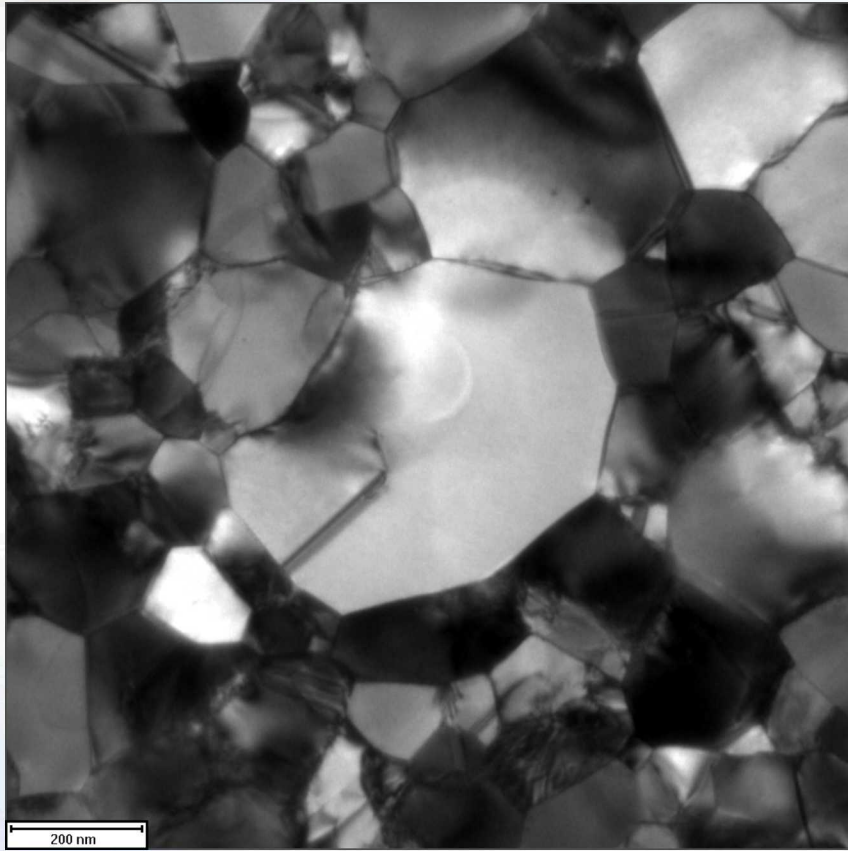
Environmental Effects

Protochips Liquid and Gas Flow

Study the material in different environments (flowing, mixing, temperature)

The application of advanced microscopy techniques to characterize synergistic effects in a variety of extreme environments

Au Film Before Implantation

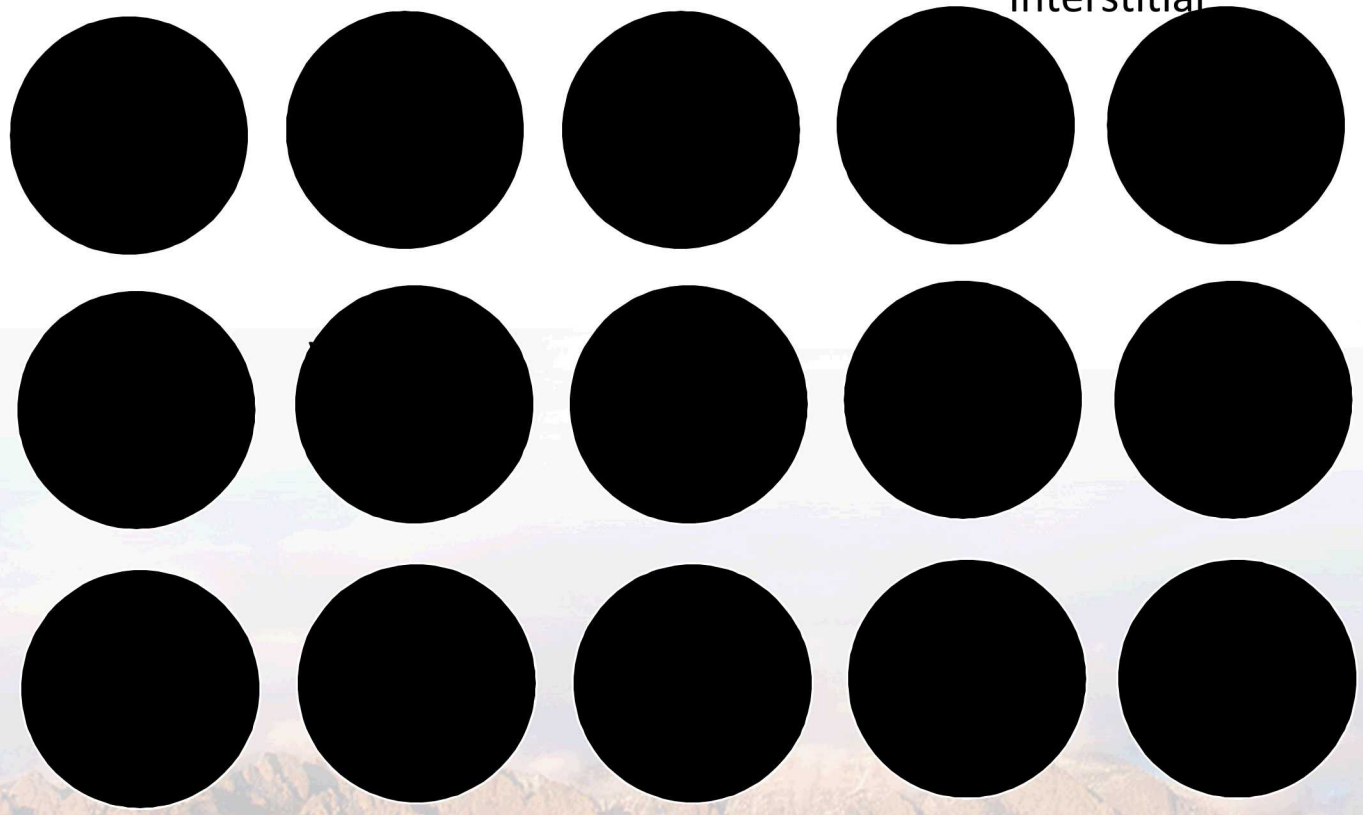


- Columnar Grains range from tens of nm to over 300 nm.
- Through-focus imaging did not reveal any pre existing cavities.



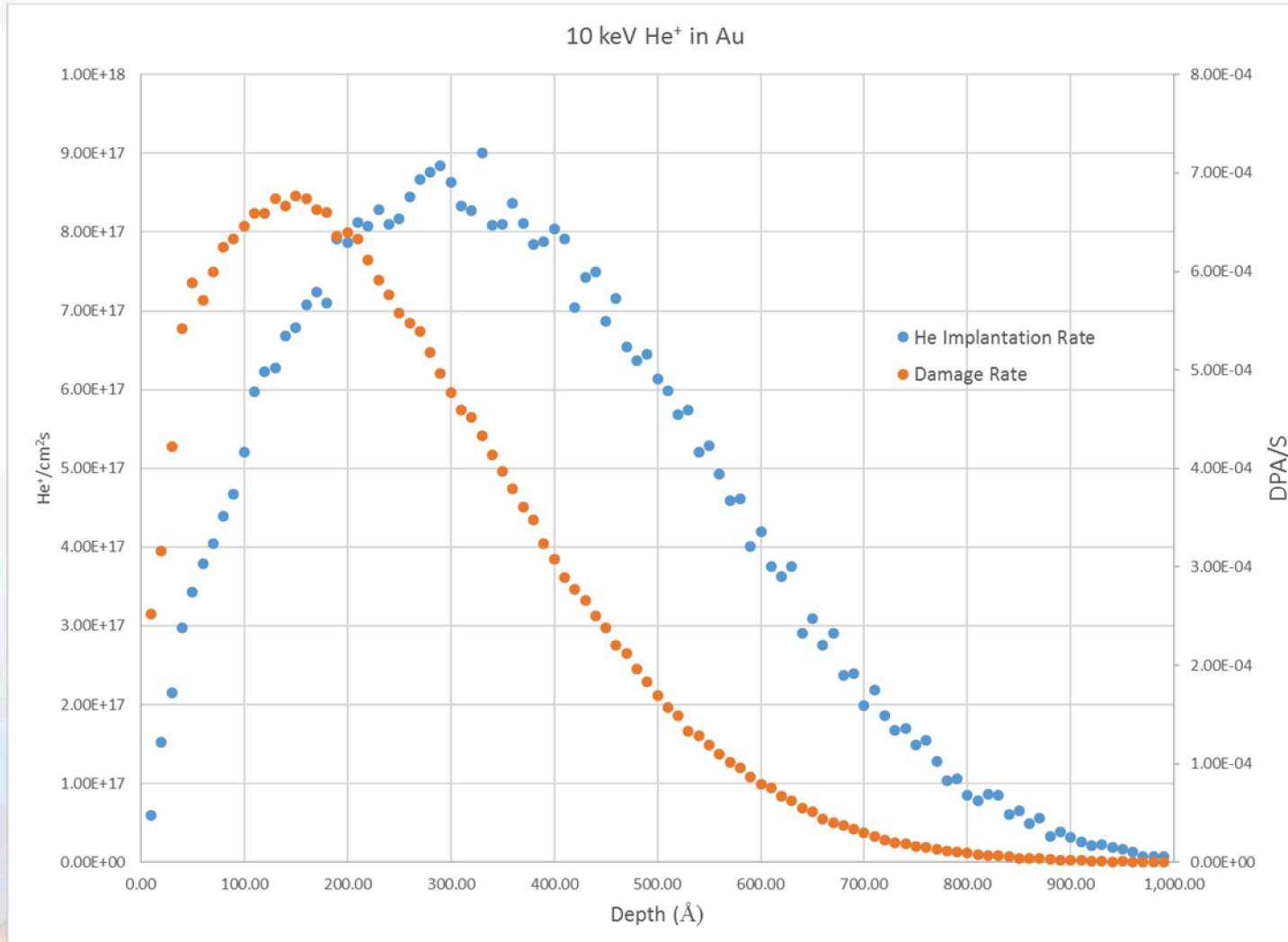
Radiation Solid Interaction

Interstitial

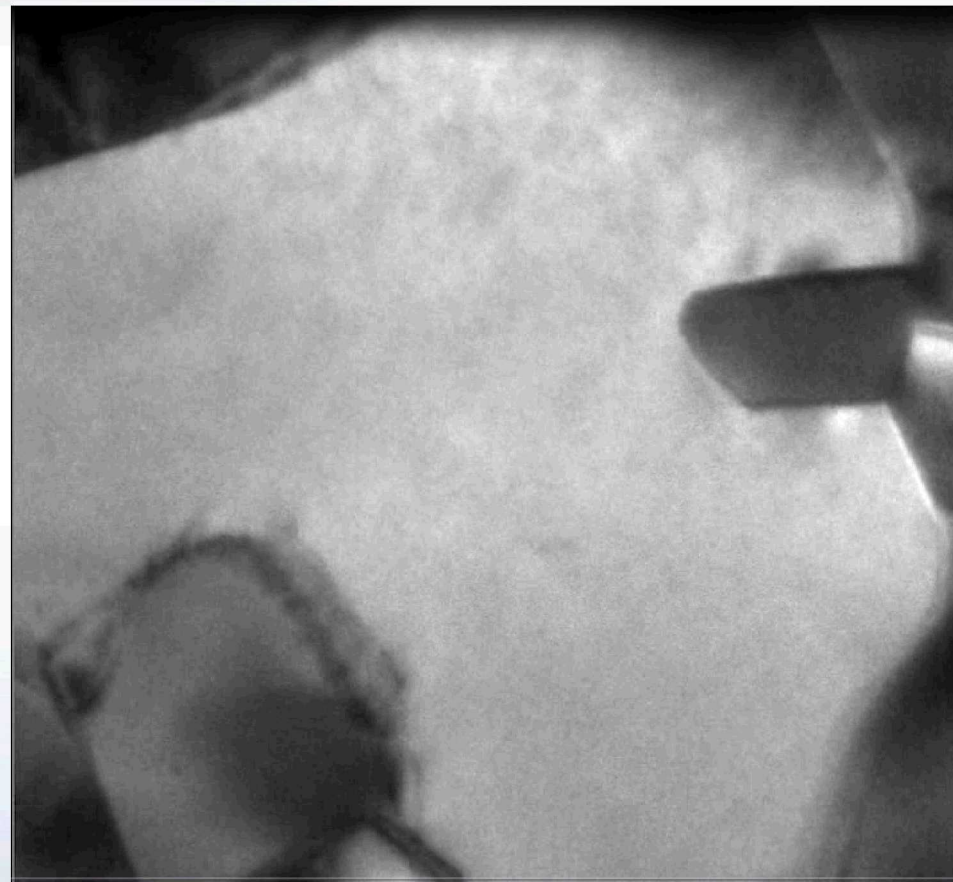


SRIM Simulation of 10 keV He⁺ in Au

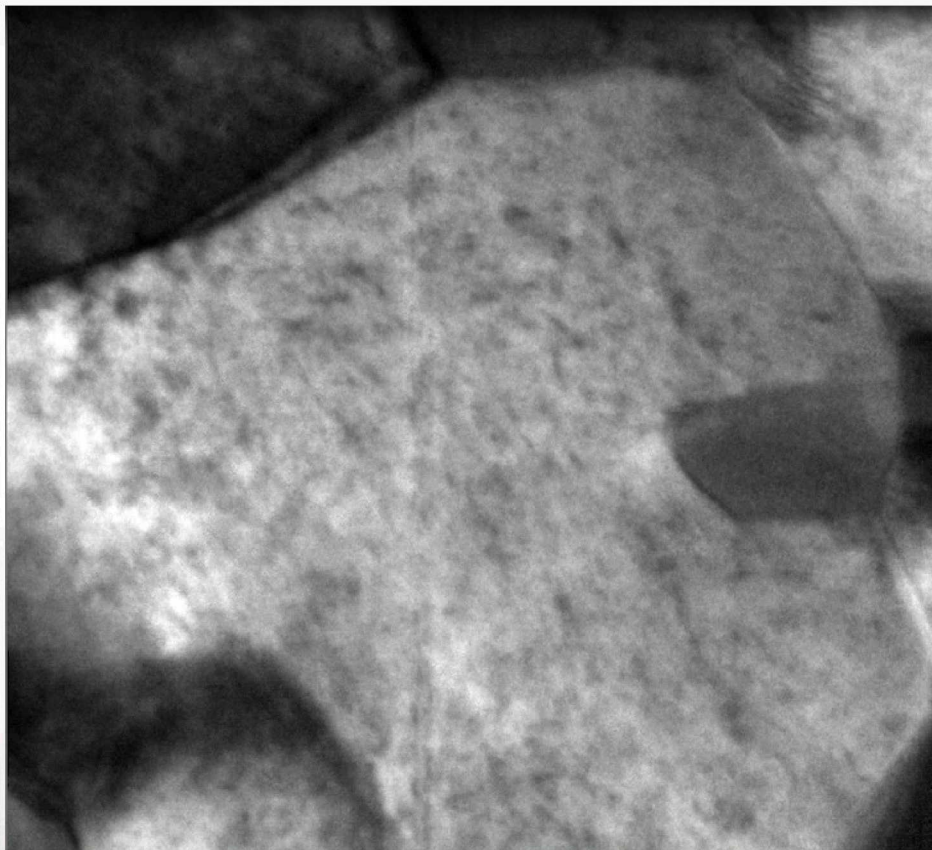
22 vacancies /ion



10 keV He into 40 nm Thick Gold Foil



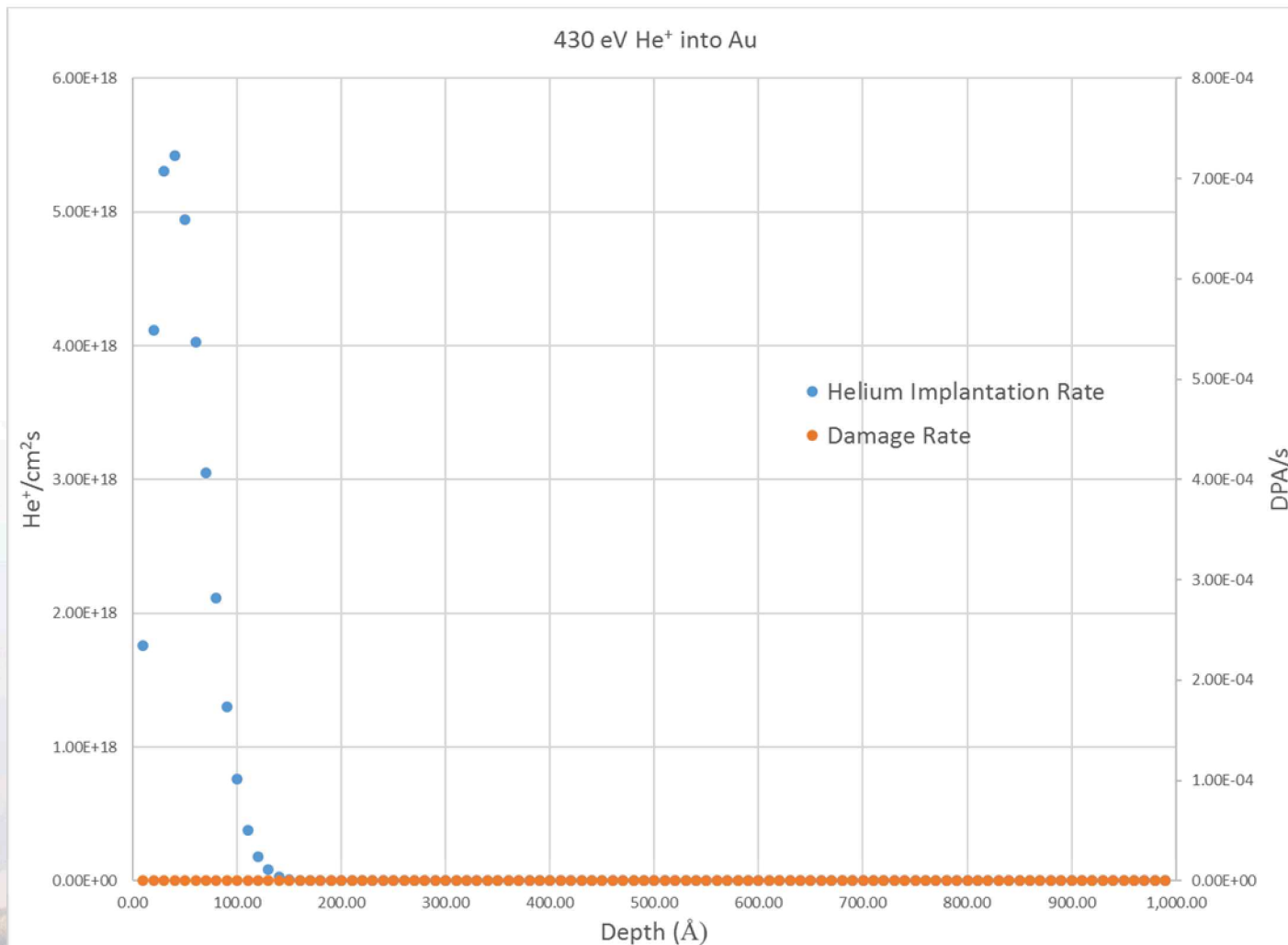
Before Implantation



After Implantation

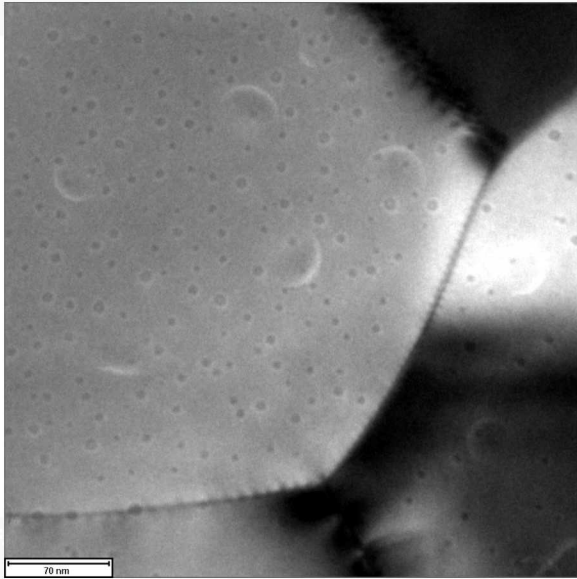


SRIM simulation of 430 eV He⁺ in Au

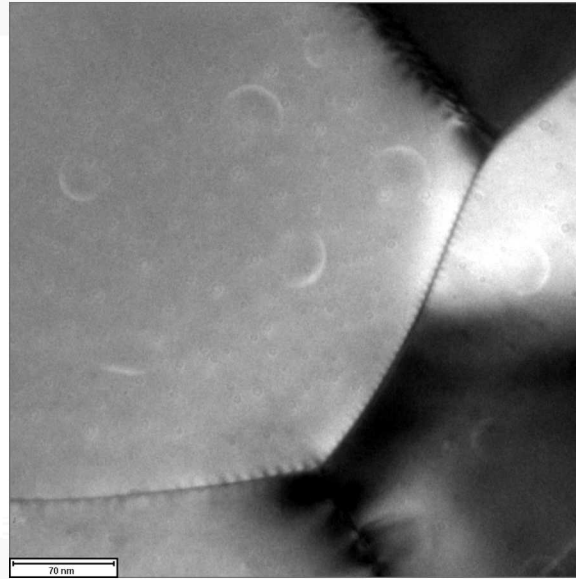


Au Film After Room Temperature Implantation

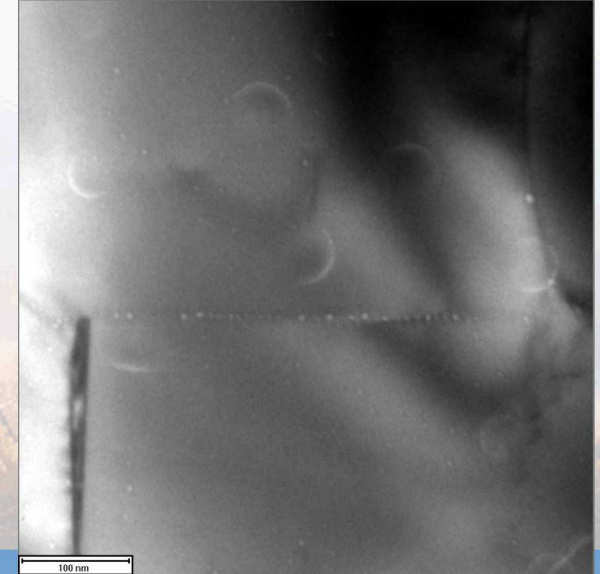
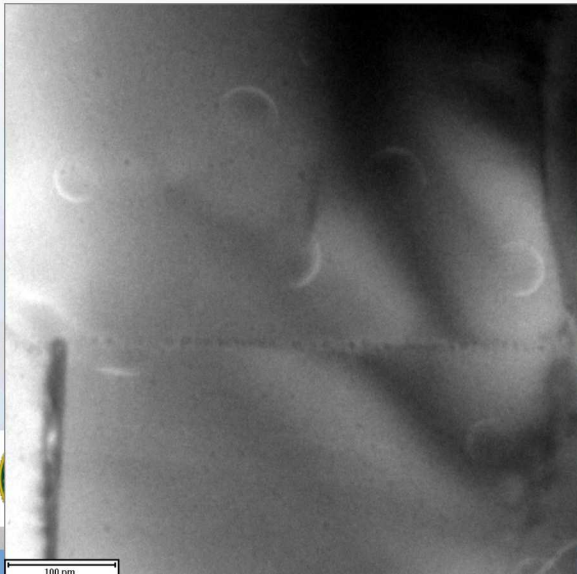
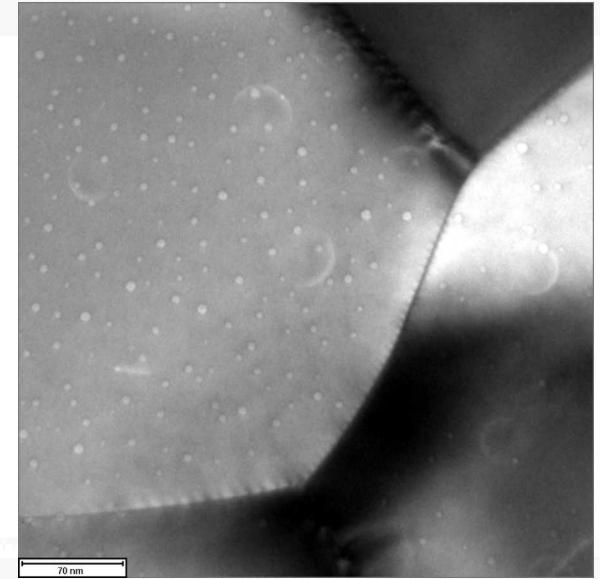
Under focus



In focus

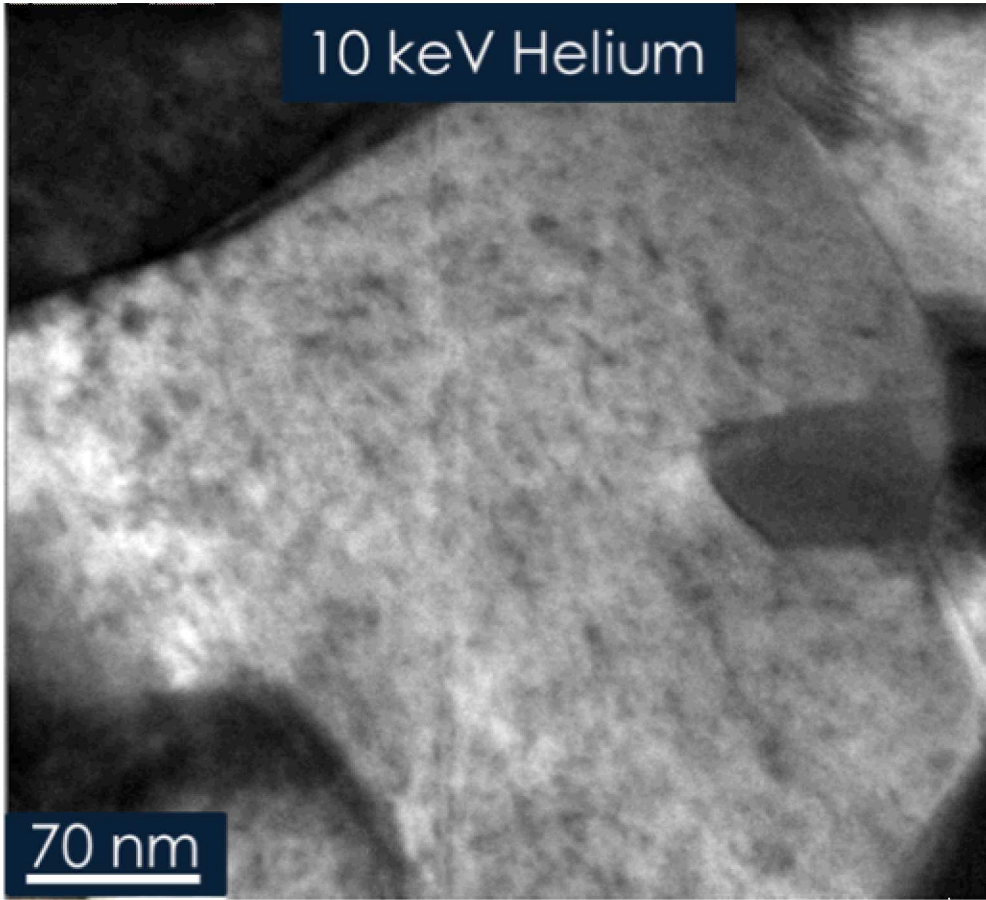


Over focus



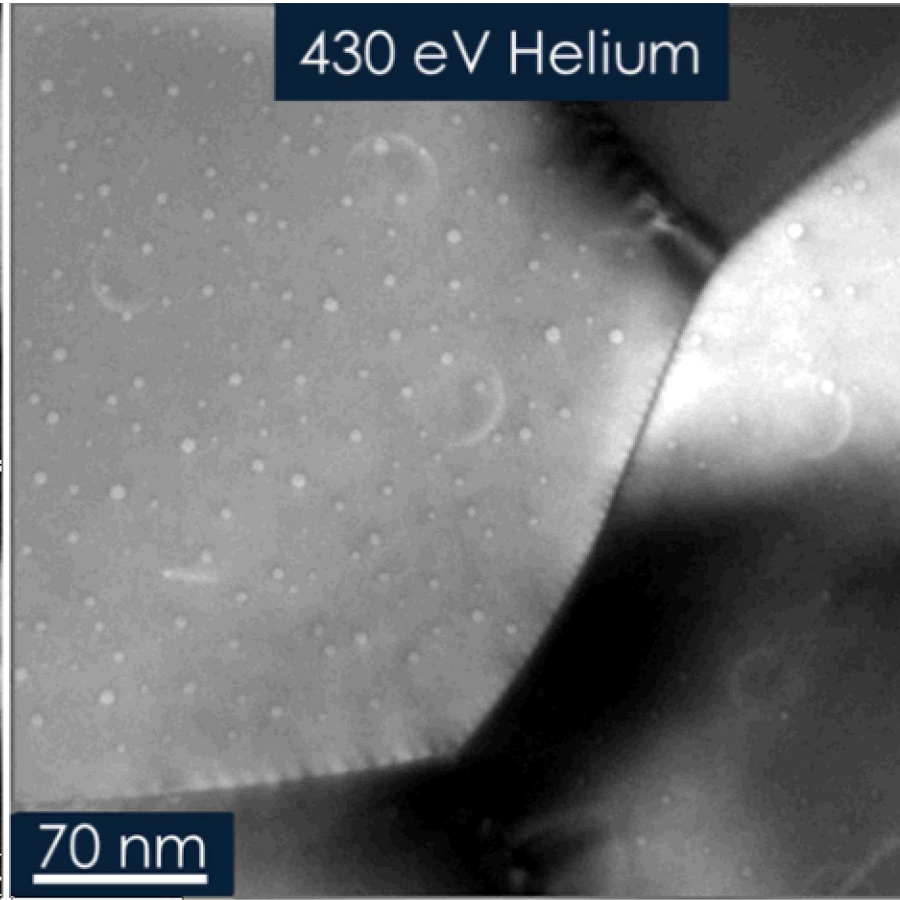


10 keV Helium



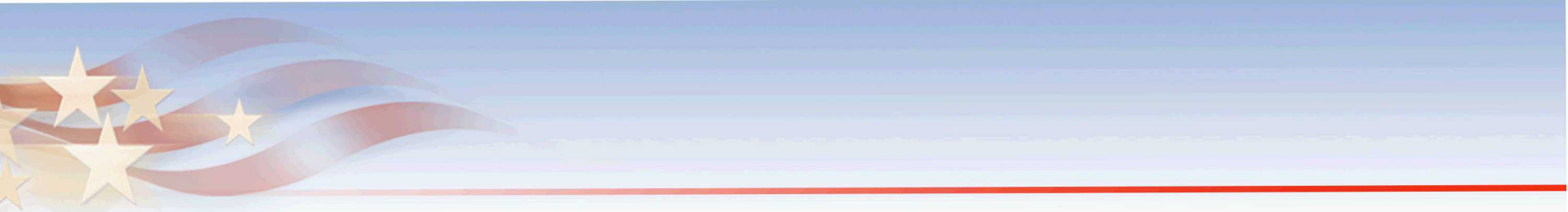
10 keV helium ions in gold foil caused displacement damage (dislocation loops & other defects) with no visible helium bubbles.

430 eV Helium



430 eV helium ions caused no visible displacement damage, and resulted in high density of helium bubbles.





Thank You!



Home Made Faraday TEM Stage

