SAND2016-10671C

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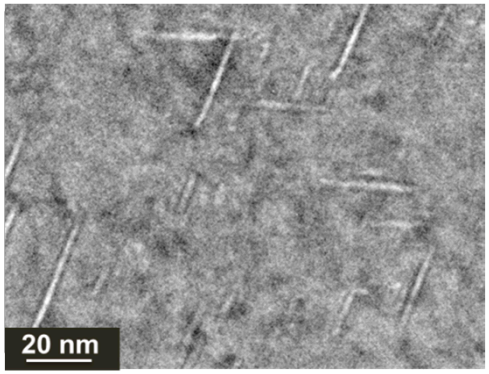

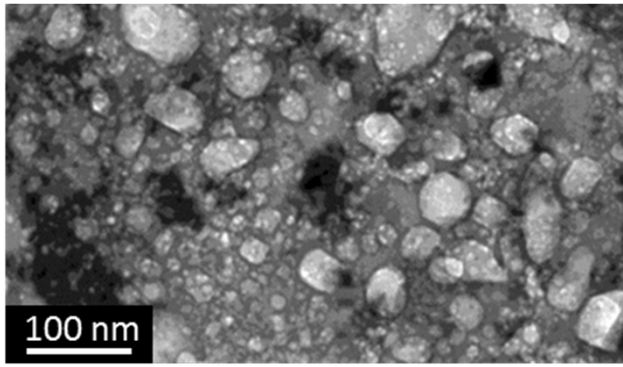

Helium Bubble Accelerated Aging

Sandra Stangebye

Brittany Muntifering, Khalid Hattar, Clark Snow, Richard Sisson

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Helium introduced into metals

- Decay of tritium – beta decay of tritium releases ^{3}He in tritium containing material

- Neutron induced nuclear reactions (n,α) – Helium can be created by nuclear transmutations of materials used in fission and fusion reactor environments

- Direct implantation - Helium can be introduced by direct implantation of plasma facing components in fusion reactors by alpha particles which escape confinement

Beta-Decay of Tritium

- Radioactive decay through emitting an energetic electron
  - Neutron is turned into a proton

$$^{3}_{1}H \rightarrow {}^{3}_{2}He^{+} + \beta^{-} + \bar{\nu}_e$$

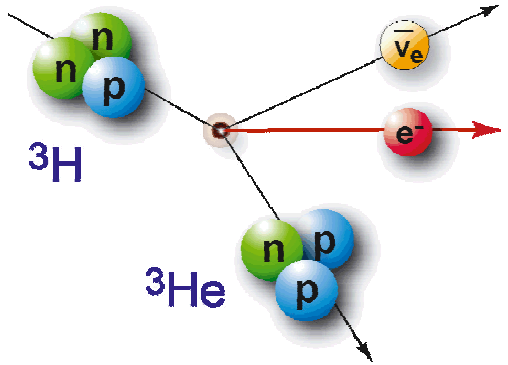
Tritium

Helium Isotope

Emitted Beta Particle / electron

Emitted Antineutrino

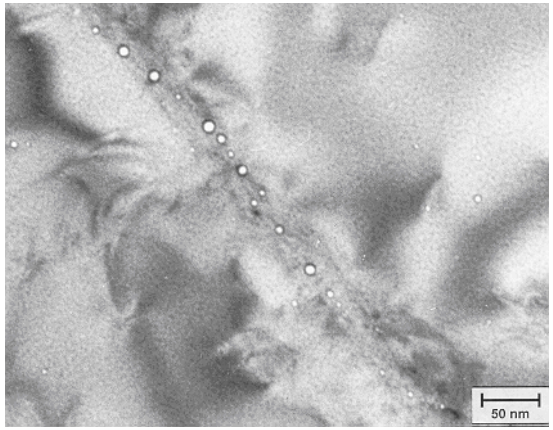
  - 12.3 year half life
  - Tritium storage materials
  - Plasma facing materials in fusion reactors



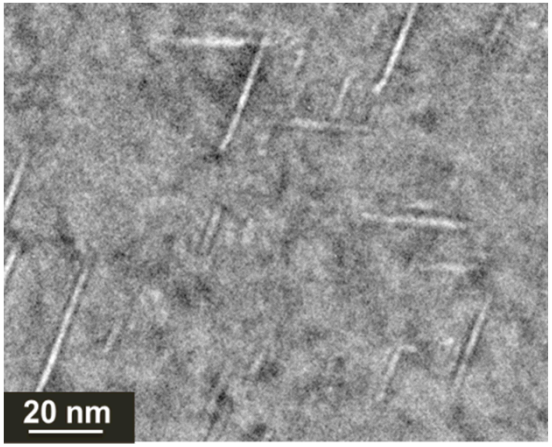
Effects of Helium Release

- Insoluble in most metals
- Forms bubbles throughout metal lattices
  - High pressure
  - Cause cracks, embrittlement, swelling and fatigue

Ultimately, Helium bubbles can cause metals to unpredictably fail and release Helium.



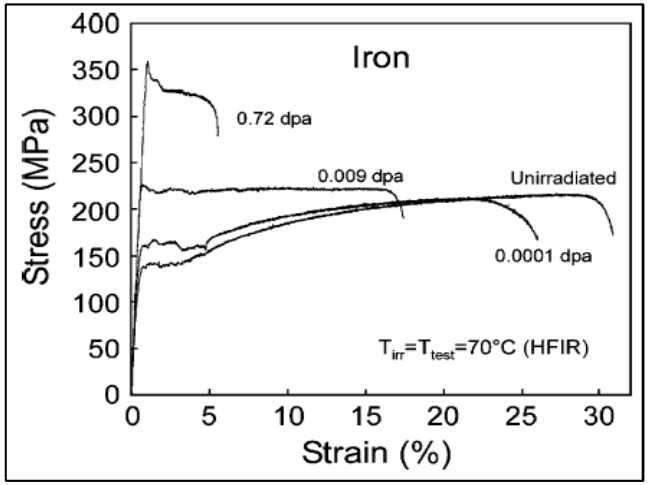
W. R. Kanne, Jr., M. R. Louthan, Jr., D. T. Rankin, and M. H. Tosten. Weld Repair of Irradiated Materials.



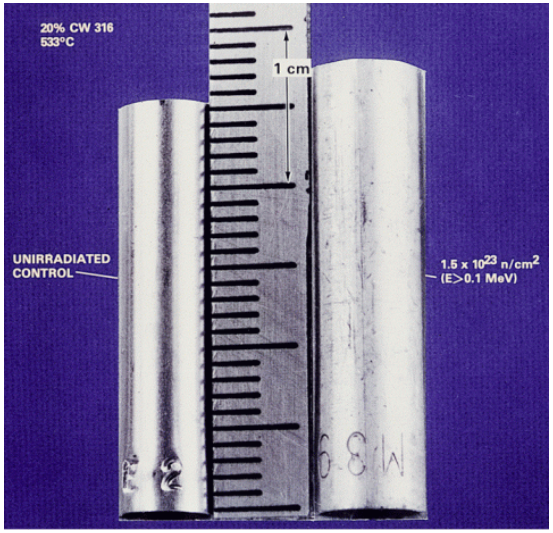
Radiation Effect on Mechanical Properties

- Yield Strength
- Ultimate Tensile Strength
- Ductile-Brittle Temperature Transition
- Young's Modulus
- Hardness
- High-Temperature Creep Rate

- Ductility
- Stress-Rupture Strength
- Density (swelling)
- Impact Strength
- Thermal Conductivity
- Electrical Conductivity



Eldrup et al. (2002)



Mansur (1994)

Limitations

- Time Consuming
- Expensive
- Radioactive
  - Difficult to prepare a radiological TEM sample

Difficult to study the behavior of helium evolution due to the fact that there is a lack of accelerated aging methods.

http://www.lboro.ac.uk/departments/chemical/enterprise/

In-Situ Ion Irradiation TEM (I3TEM)

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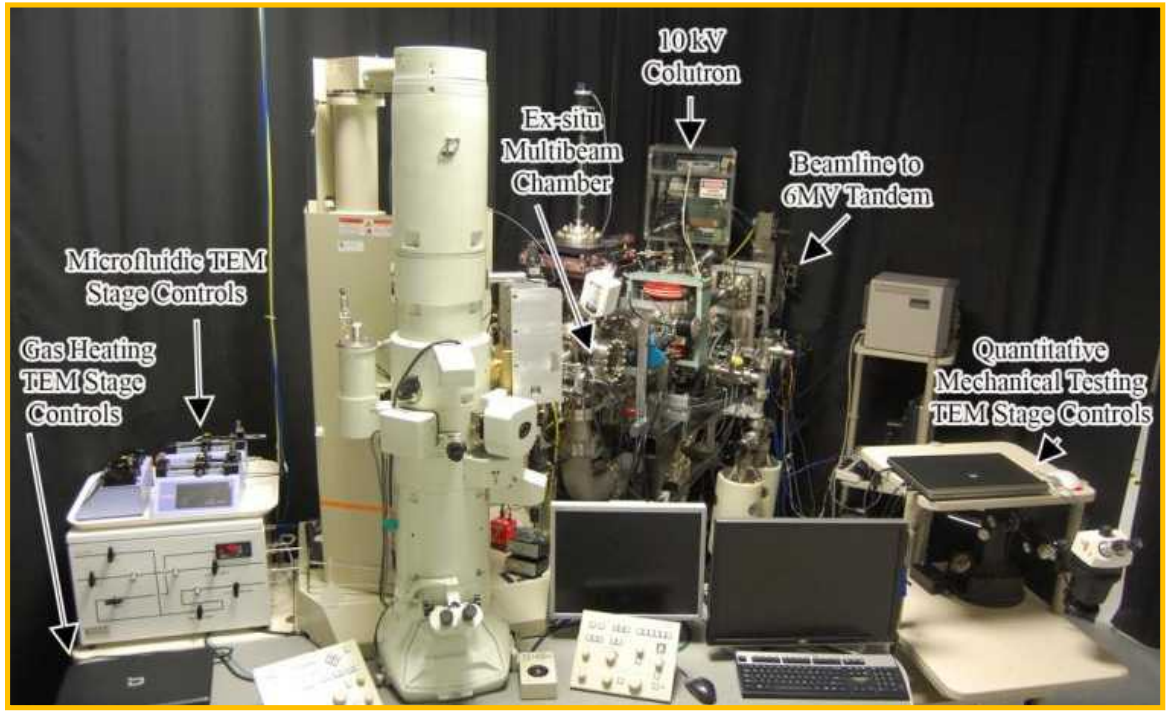
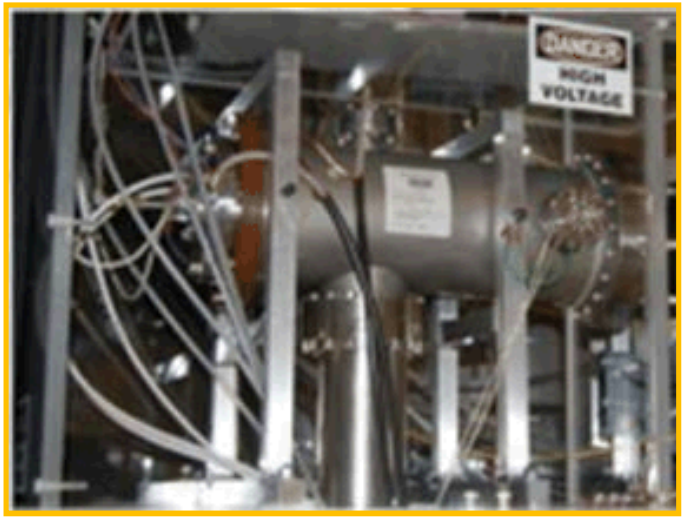


200 kV JEOL 2100 TEM

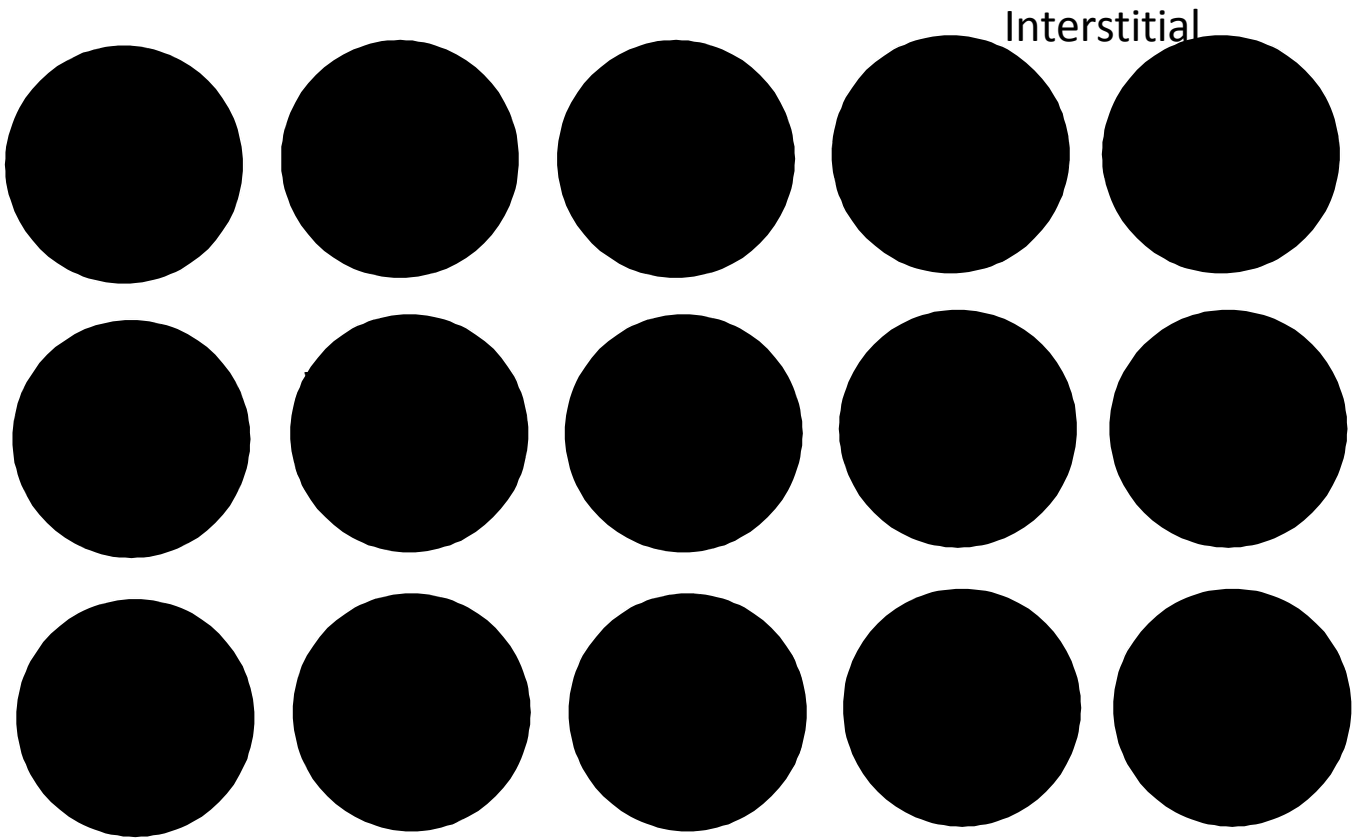


Colutron Ion Accelerator

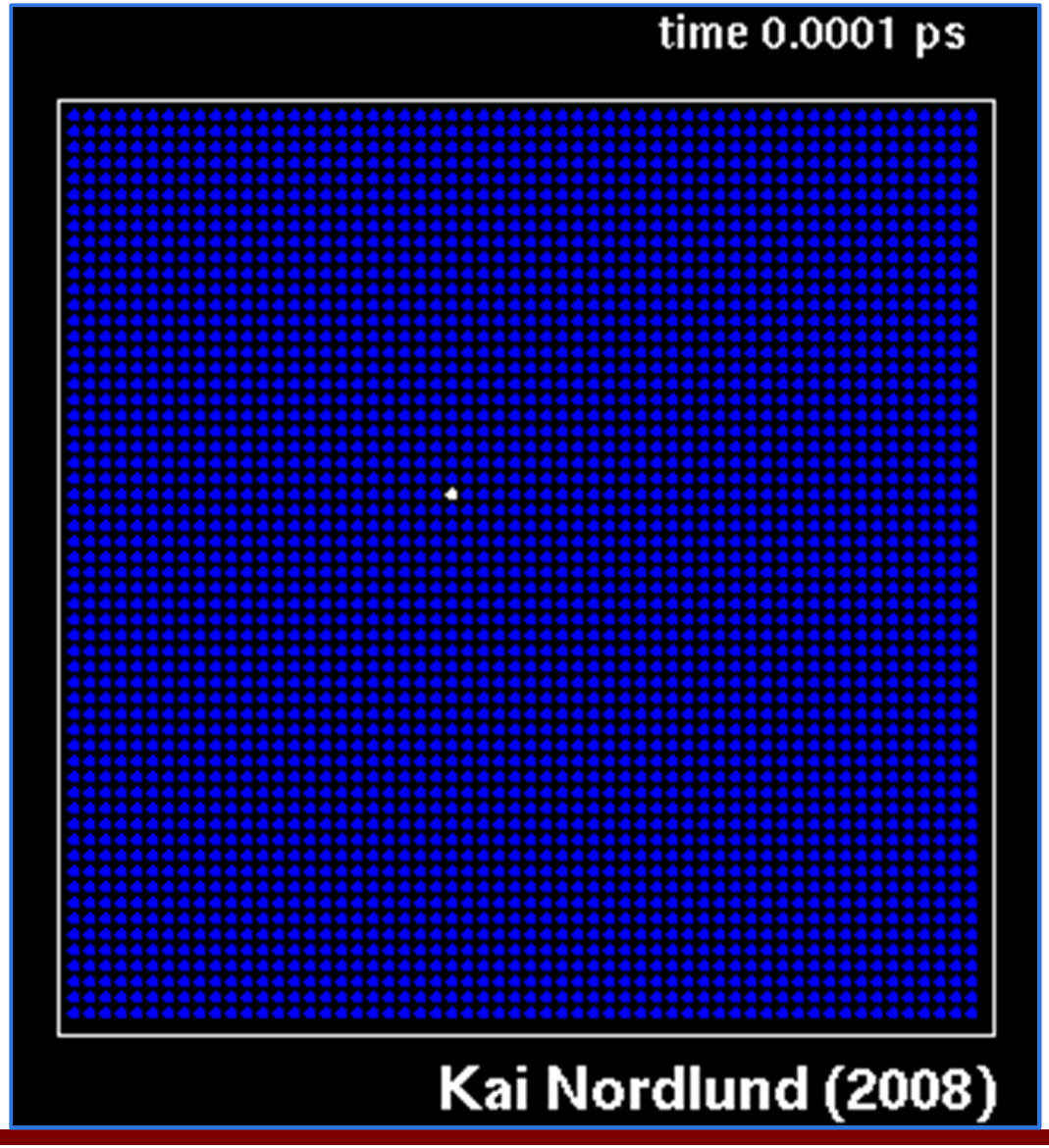
Implant helium ions with energy from 100s of ev to 10s of keV

This allows real time observation of Helium implantation, nucleation, bubble evolution and fracture. This saves a tremendous amount of time.

Radiation Solid Interaction

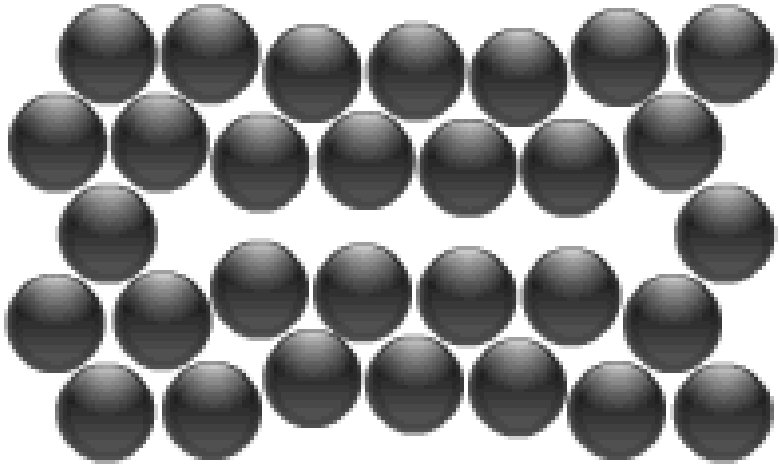


Radiation-Solid Interaction

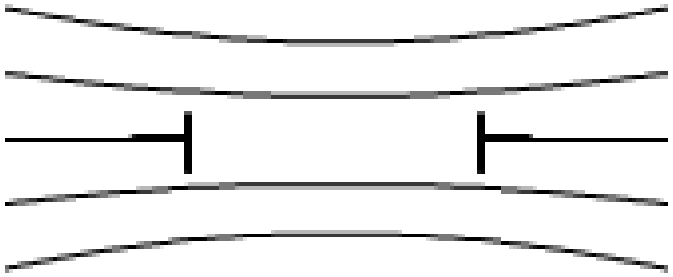


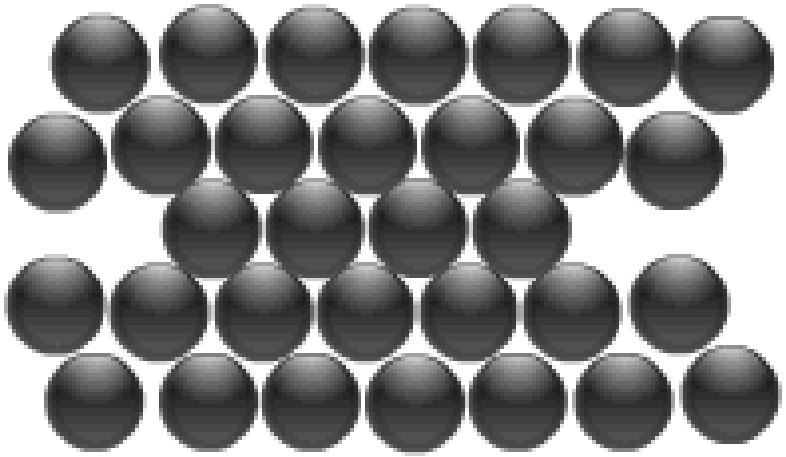
Implanting ions can cause a cascade of stable defects

Microstructure Defects: Dislocation Loop

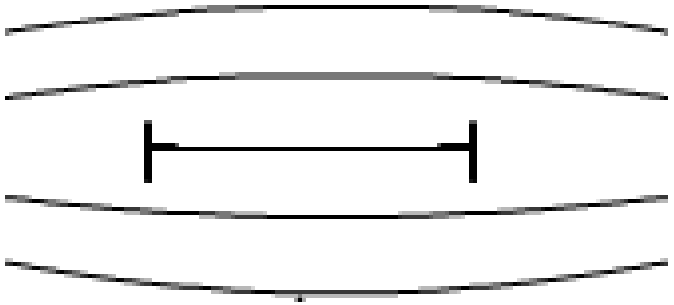


Vacancy Loop

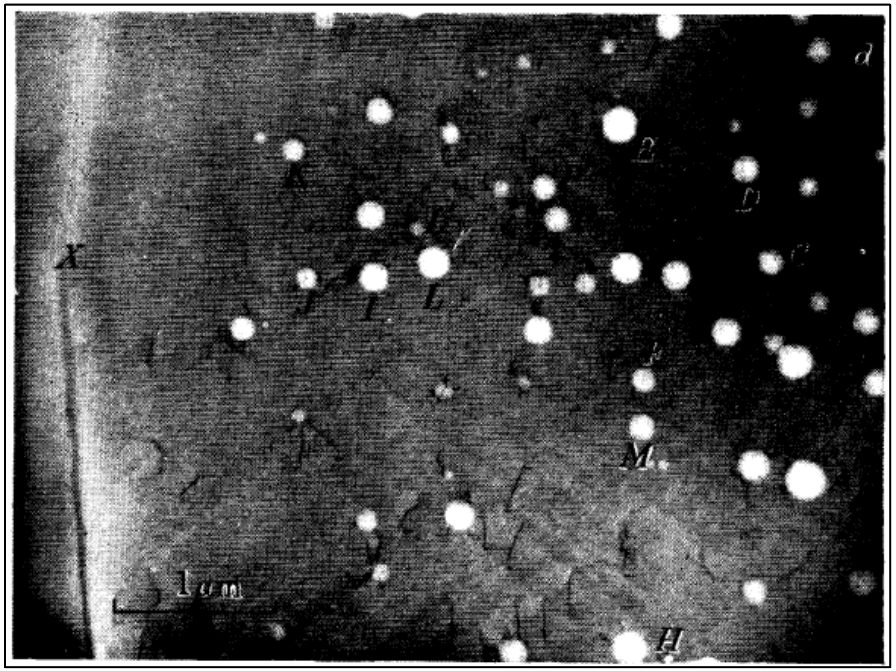




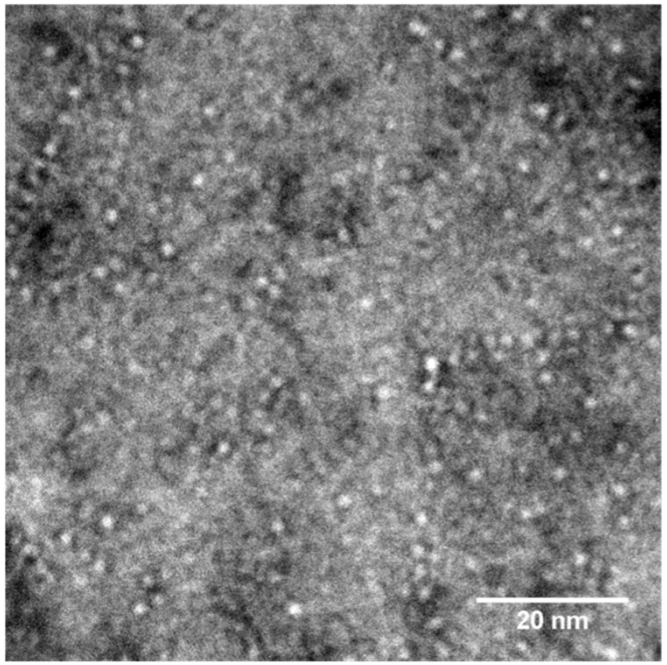
Interstitial Loop



Microstructural Defects: Cavities

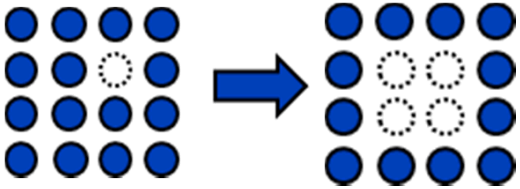


Voids

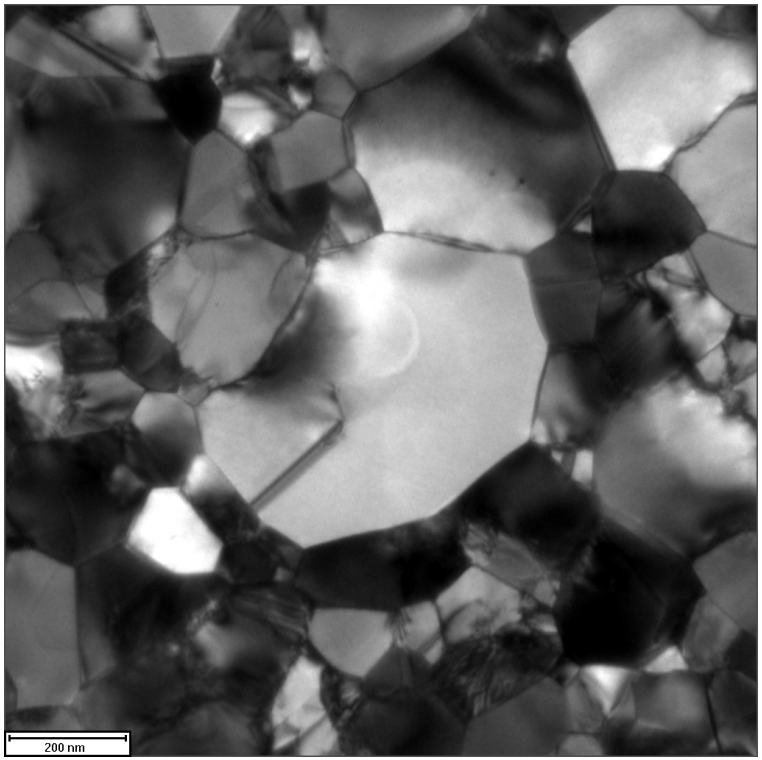


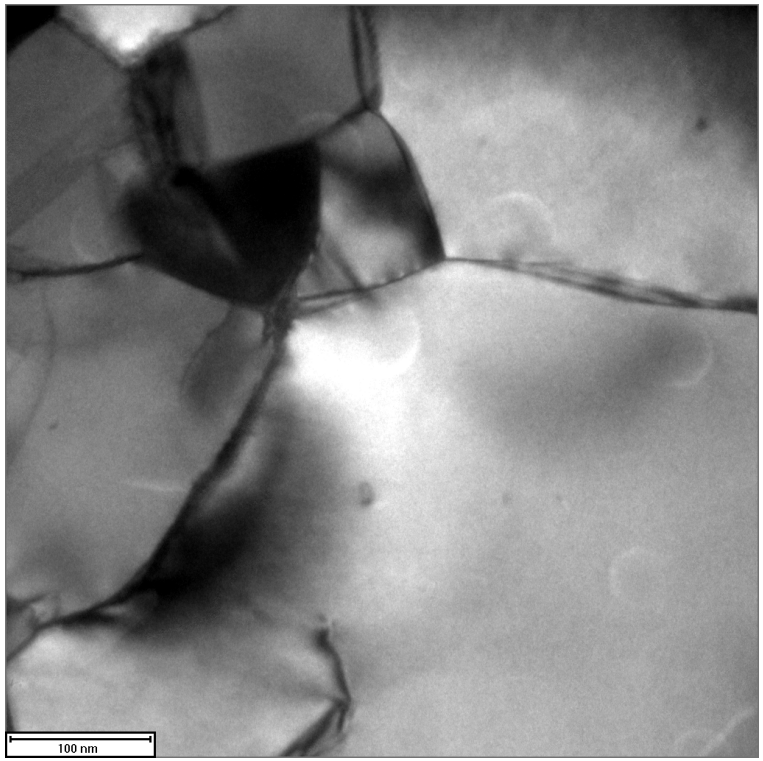
Helium Bubbles

Vacancy Diffusion Vacancy Clusters



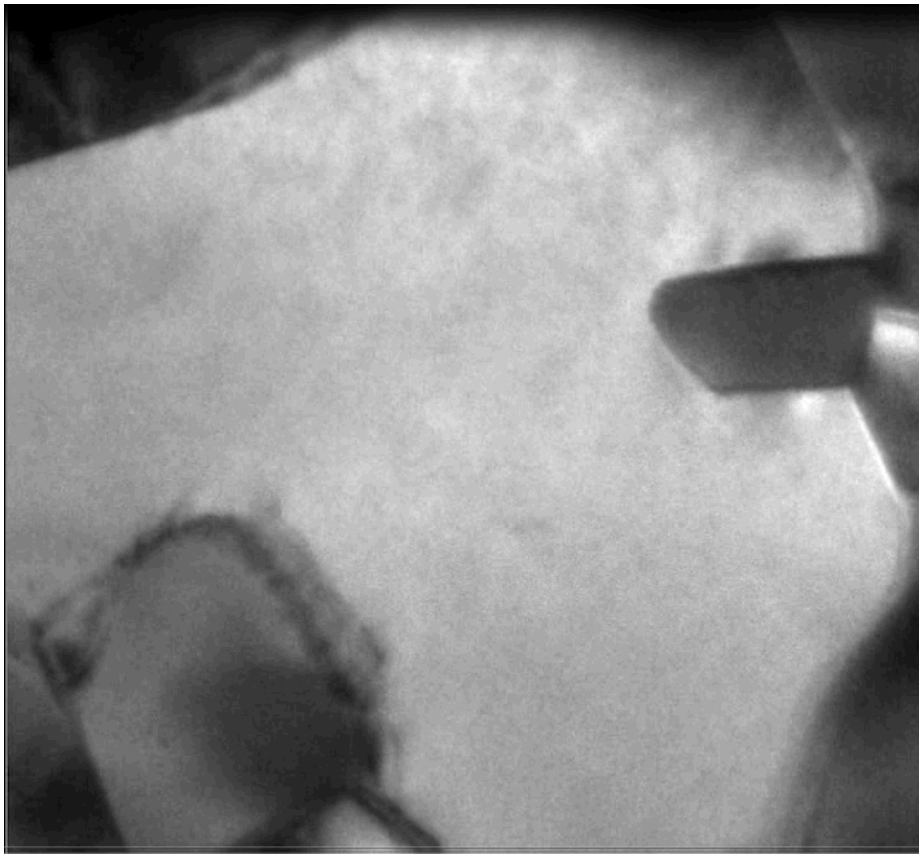
PLD Au Films Before Implantation



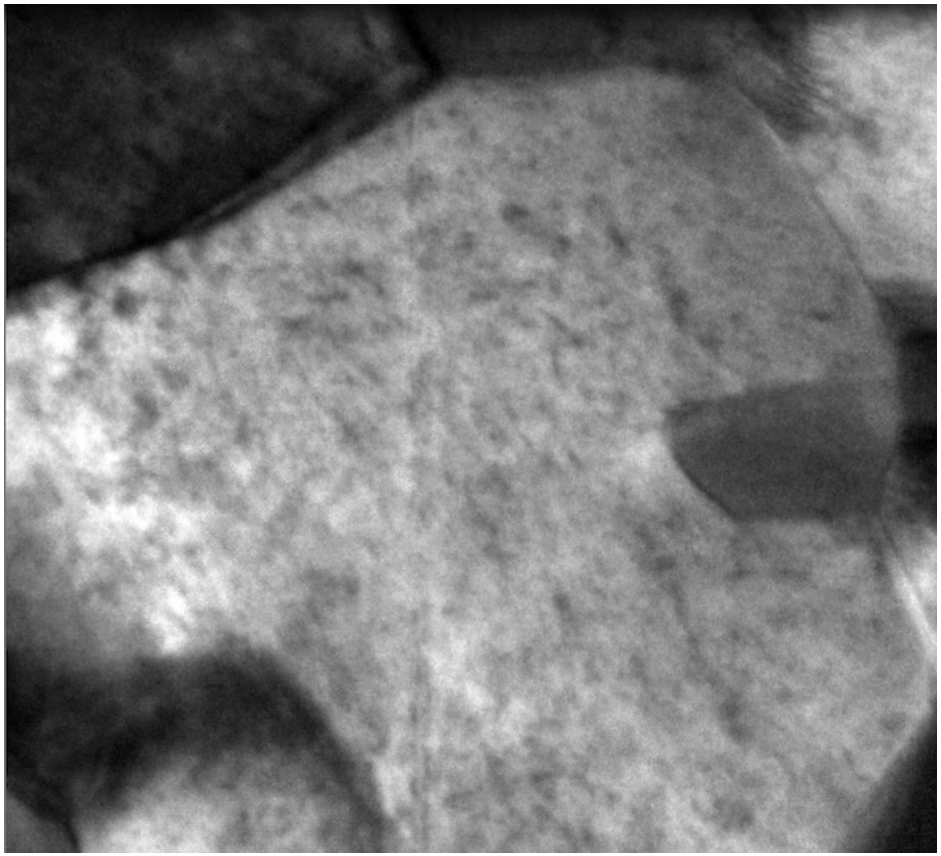


- Pulsed Laser Deposition
- Annealed to 300C
- Grains range from tens of nm to over 300 nm.
- Through-focus imaging did not show any pre existing bubbles

10 keV Implantation into 40 nm Thick Gold Foil



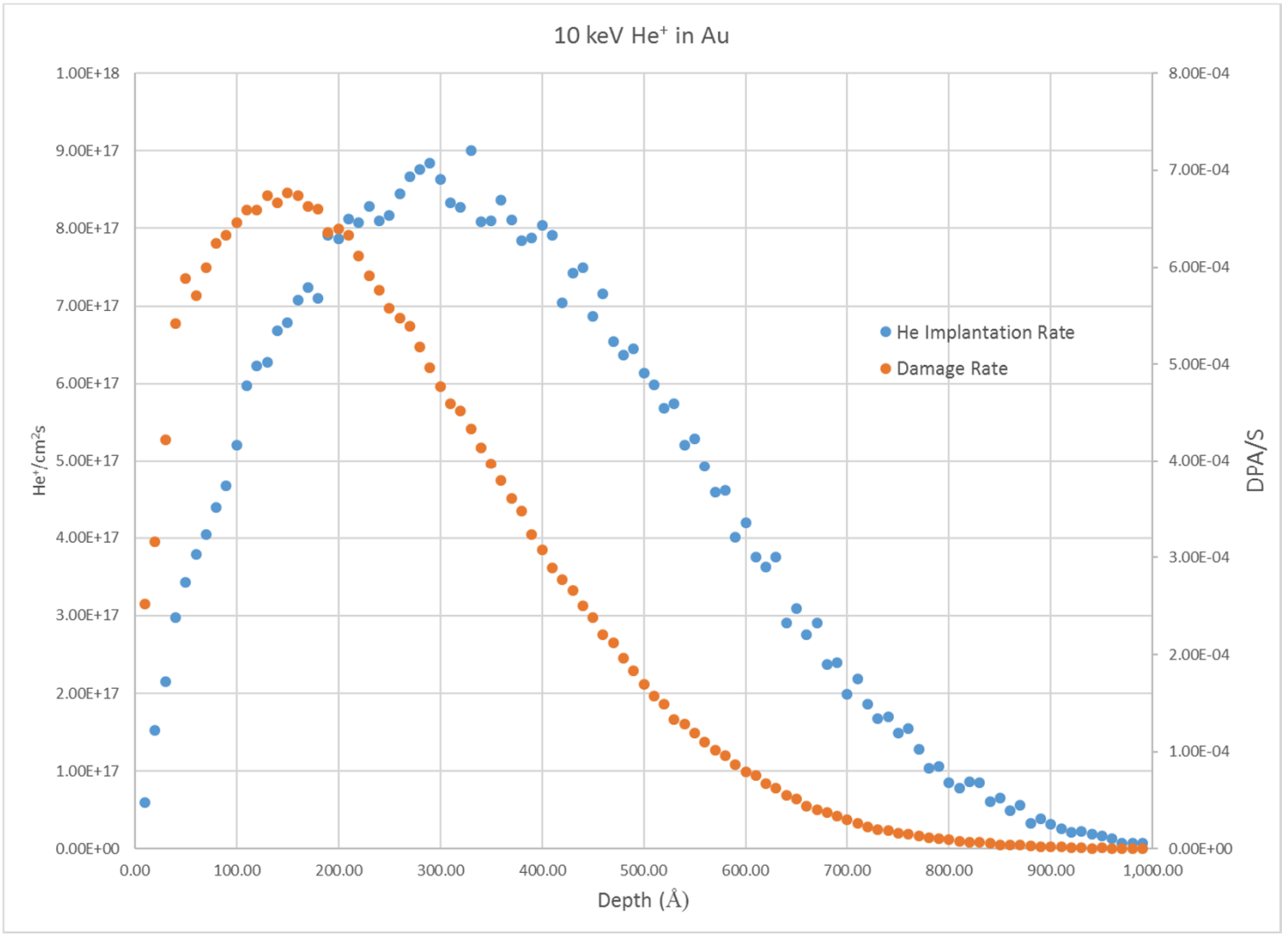
Before Implantation



After Implantation

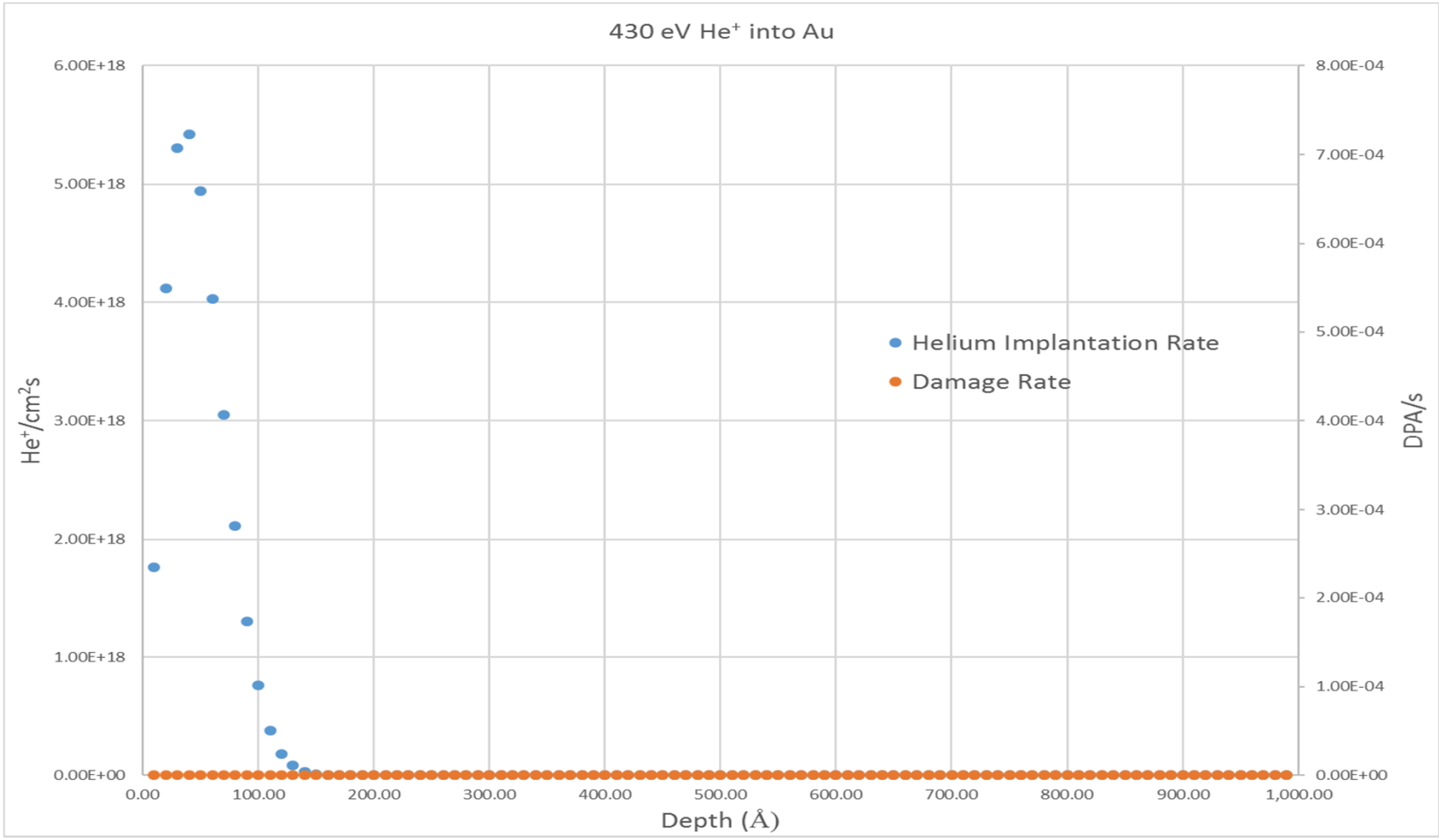
A lot of “Black Spot” damage is seen

SRIM Simulation of 10 keV He^+ in Au



- Enough energy to implant Helium into the middle of the film.
- causes a high damage rate.

Using a Lower Energy



SRIM simulation of 430 eV He^+ in Au

Au Films After Room Temperature He Implantation of 430 eV

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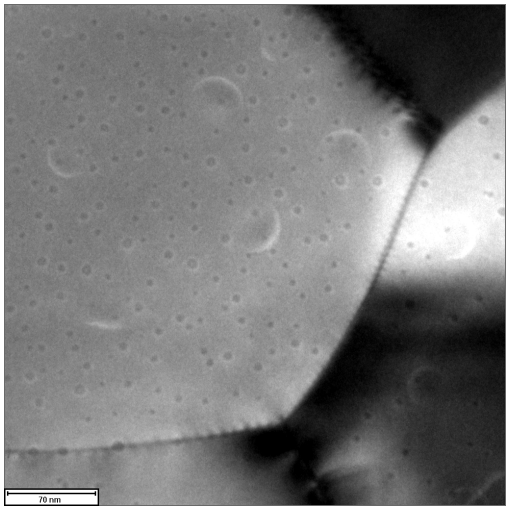
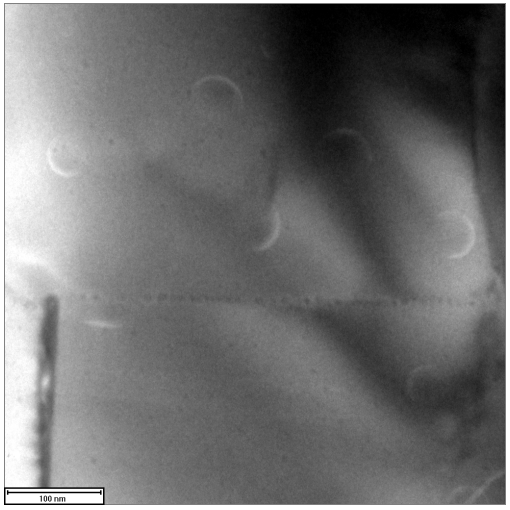
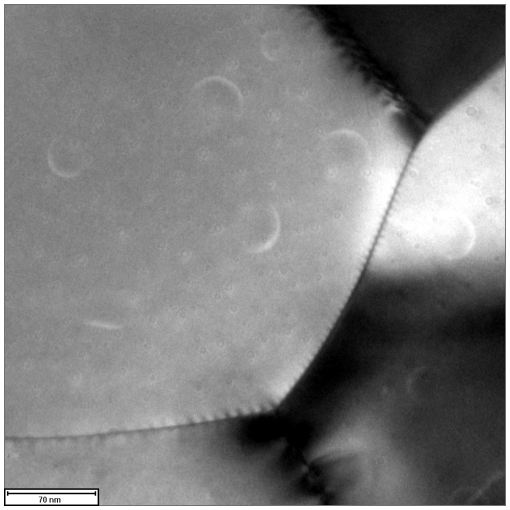
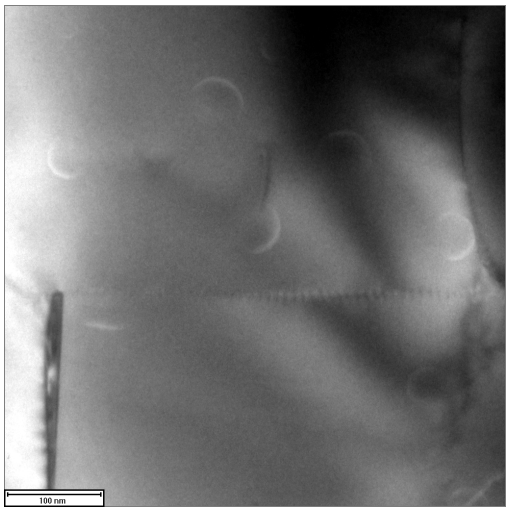
Under focus



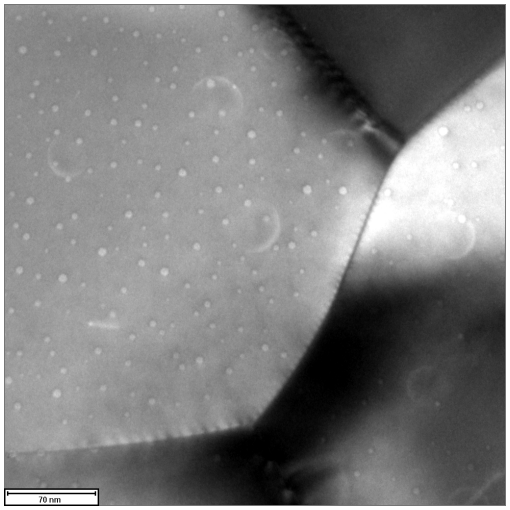


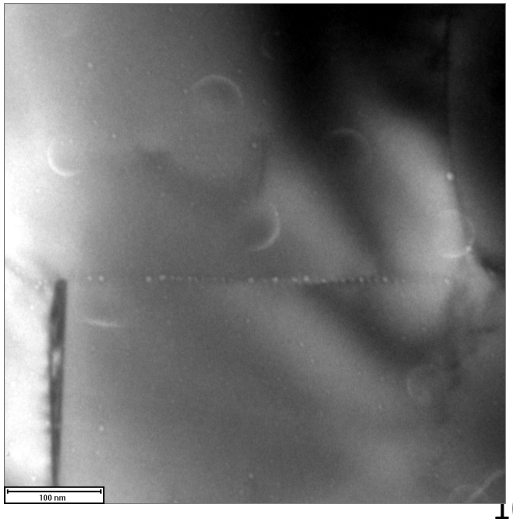
In focus





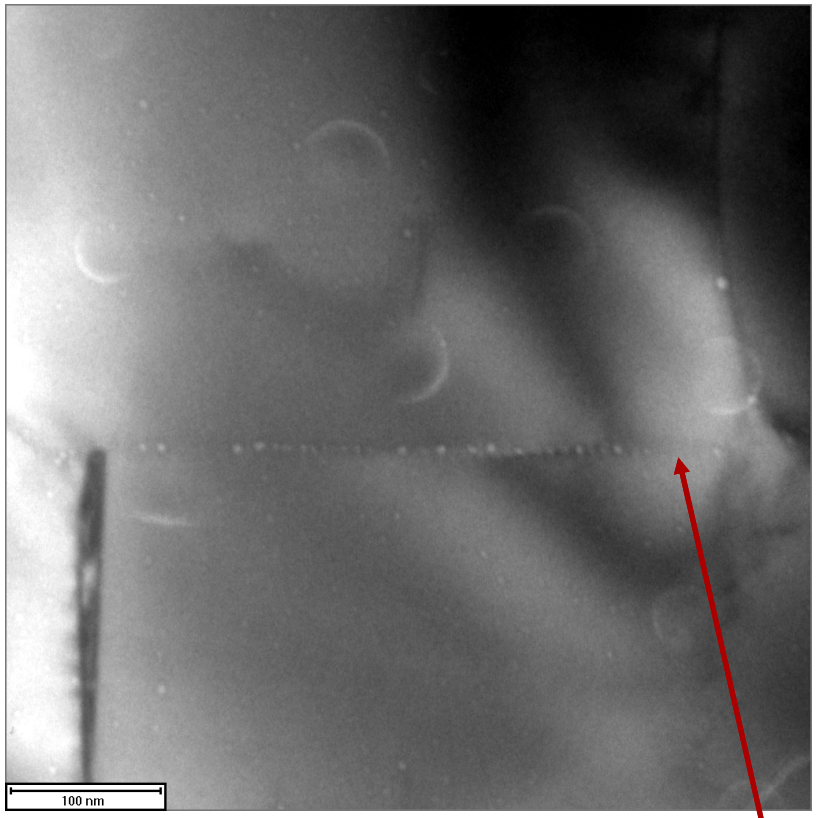
Over focus

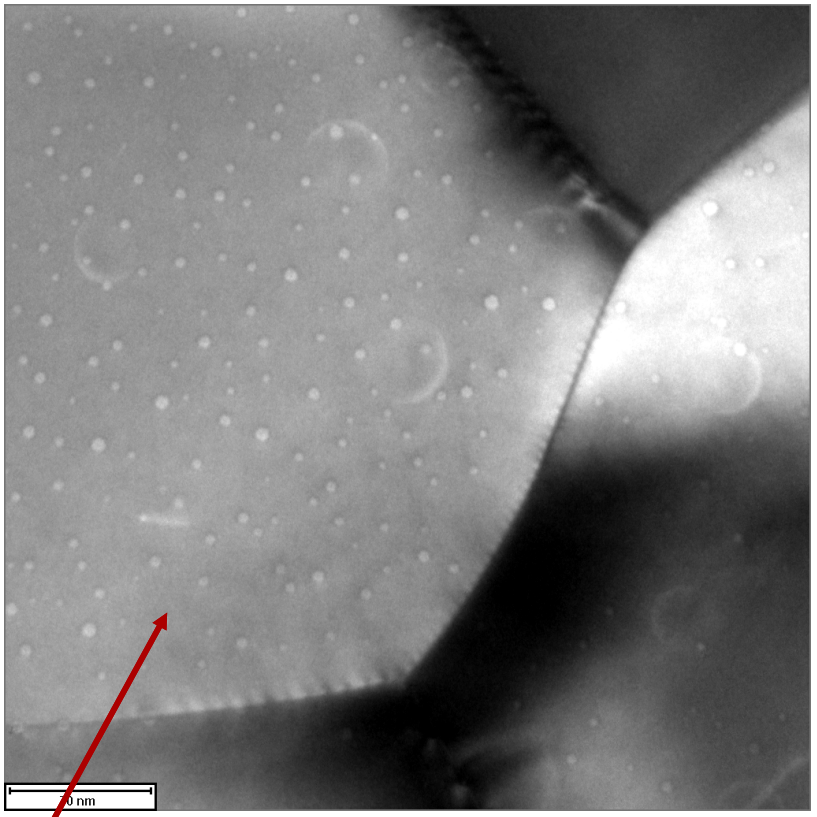




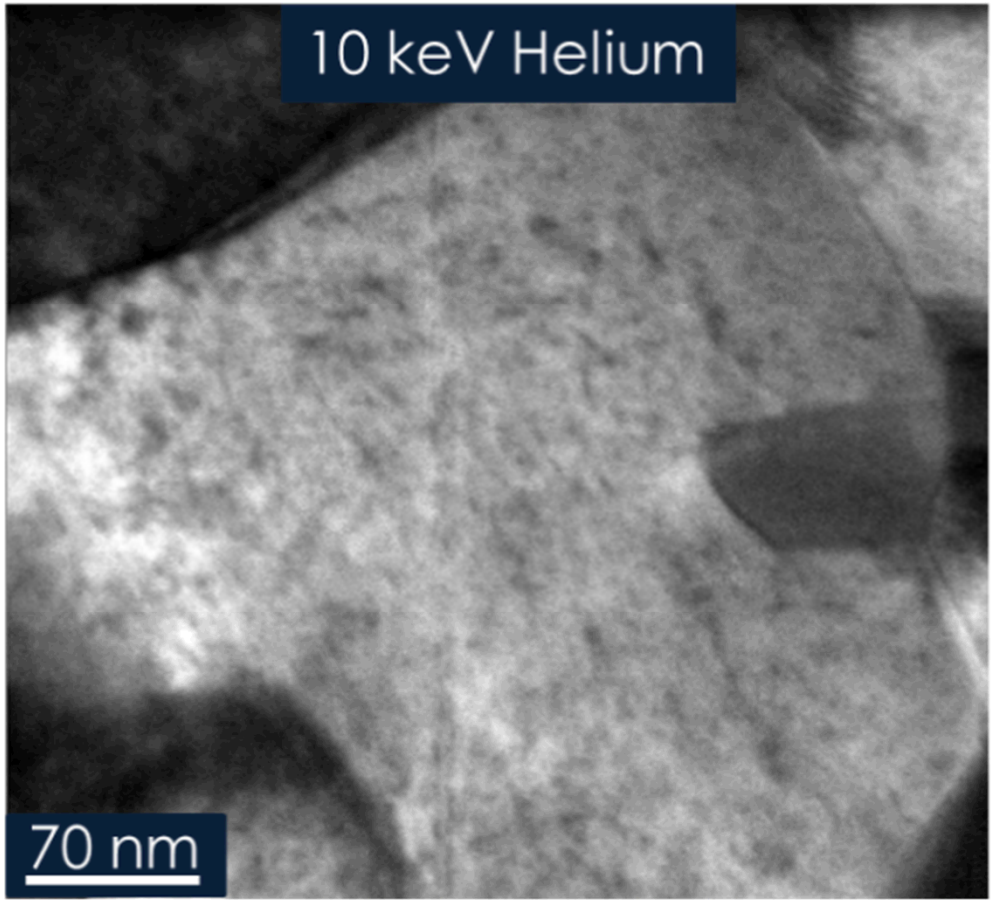
Bubbles Present

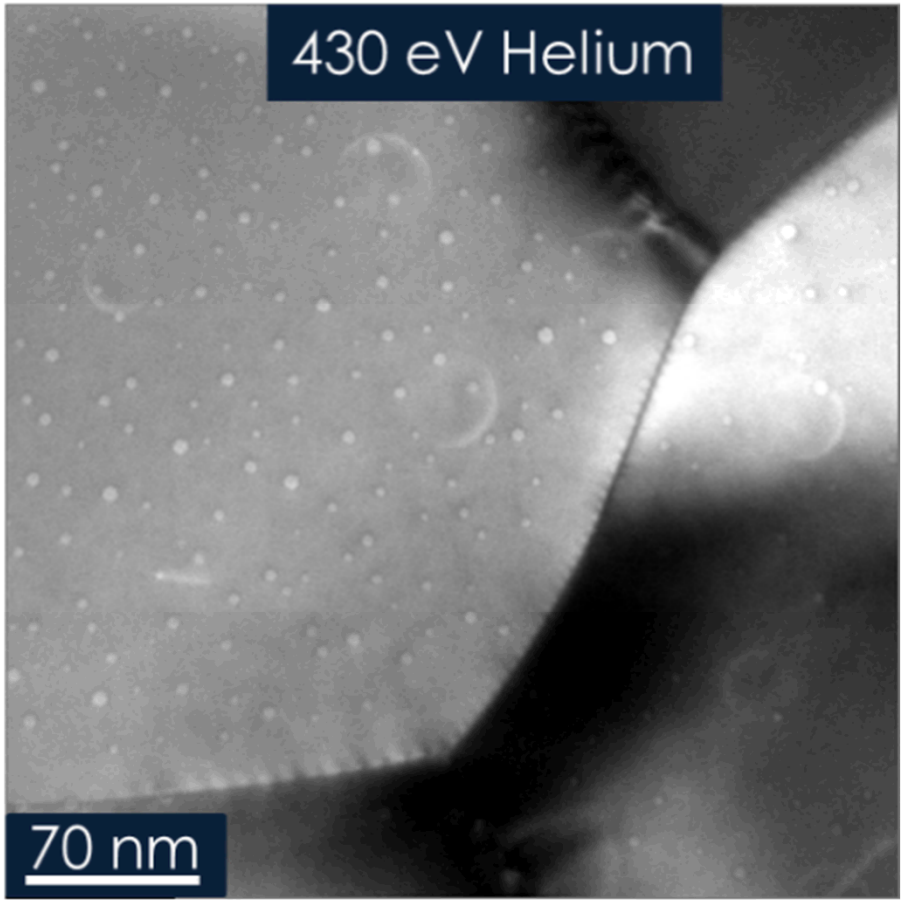
Over focus





Bubble can be seen along the grain boundary as well as within the grains





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

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

Conclusion

- Successfully implanted low energy Helium into Au thin film
- This new technique developed will allow more research into Helium present in metals due to beta-decay of tritium.
- Next step – develop a technique to allow in-situ implantation of low energy Helium inside the TEM