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Time-Resolved 3D Imaging of Ion Beam-Induced Surface Damage in Gold Nanoparticles

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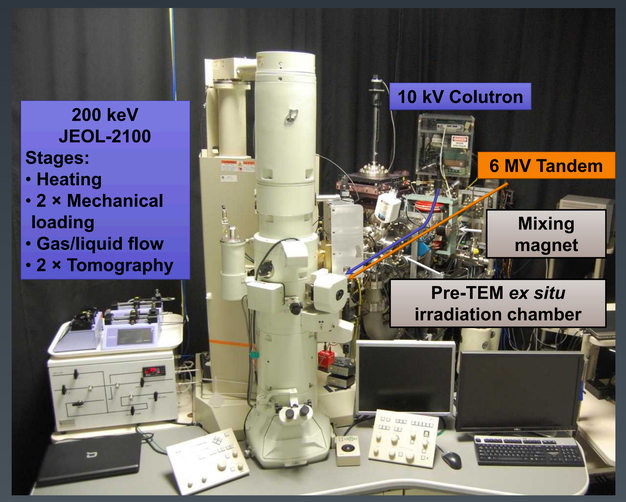
Motivation

- Nanoparticles have electrical, chemical, and optical properties tied to their shapes and sizes.
- Energetic particles may alter these attributes.
- It is important to understand radiation effects in these materials in order to:

1. Ensure stability in radiation environments
2. Tailor properties through ion beam modification.

The Microscope



I^{3}TEM Facility

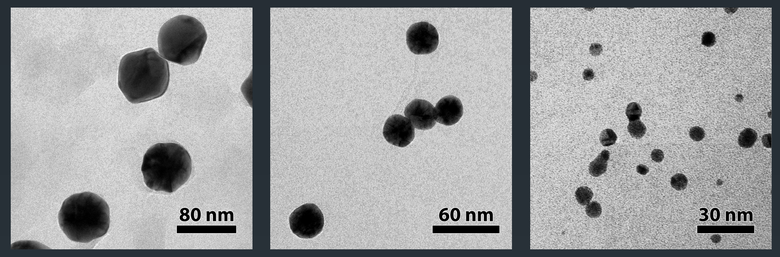
- TEM with two ion accelerators attached and a suite of *in situ* sample manipulation capabilities
- Hummingbird single tilt (±81°) and Gatan double tilt rotation tomography holders

Goals and Approach

Characterize changes in cluster and surface morphology over time

- Alternating *in situ* irradiation in the TEM and tomography

As-Cast Nanoparticles

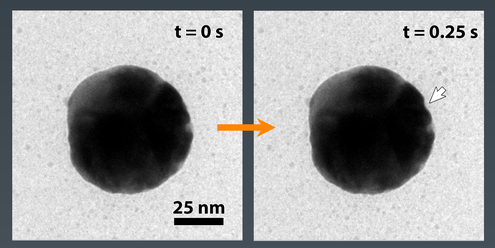


Left to right: 60, 20, and 5 nm diameter Au nanoparticles

- Samples on α-carbon/Cu grids
- Individual particles and clusters for observation

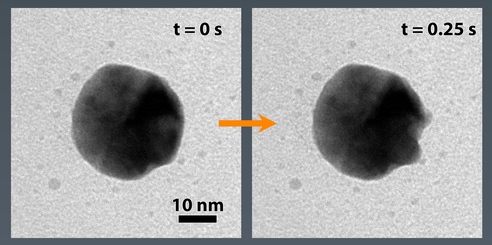
Changes Observed *In Situ*

Particle size and ion energy-dependent behavior



Single-ion events

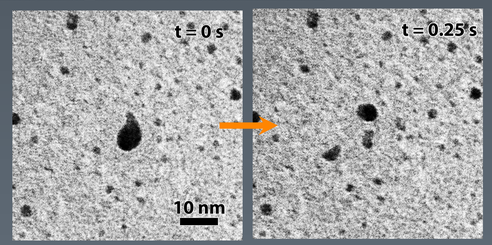
- 46 keV Au$^-$



Top: cratering in a 60 nm diameter particle

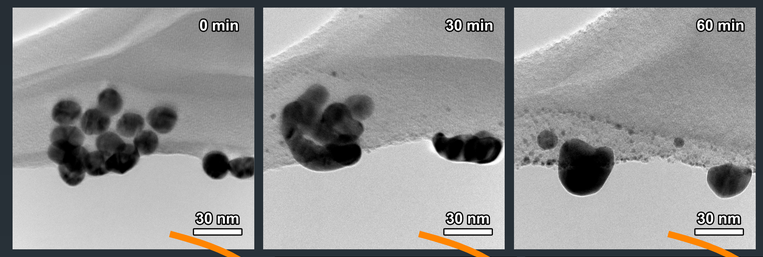
Middle: cratering in a 20 nm diameter particle

Bottom: explosion of a 5 nm diameter particle



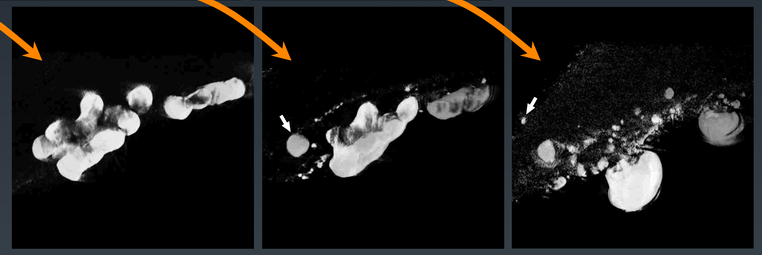
20 nm Au Nanoparticles

In situ irradiation with 3 MeV Cu^{3+}



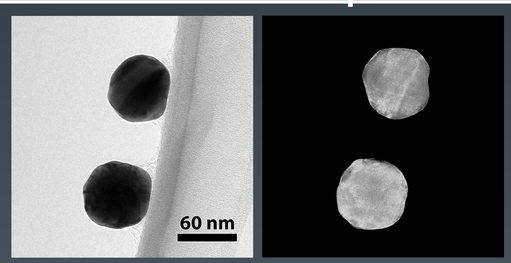
Left: TEM micrographs of nanoparticles at 0, 30, and 60 minutes (0, 1.6, 3.1 × 10^{15} ions/cm^2)

Right: Tomograms provide a more complete view of irradiation-induced sintering and ablation.



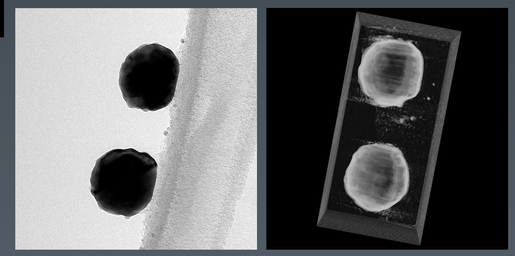
60 nm Au Nanoparticles

In situ irradiation with 2.8 MeV Au^{4+}



Left: As-cast nanoparticles and corresponding tomogram

Right: TEM micrograph and tomogram showing individual surface defects after 2.0 × 10^{14} ions/cm^2.



Conclusions

3D reconstructions enhance visualization of ion effects in nanoparticles

- Sintering and ablation in smaller nanoparticles
- Surface craters and bumps in larger nanoparticles
- Reveals the potential for creating unique surface structures via ion interactions

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