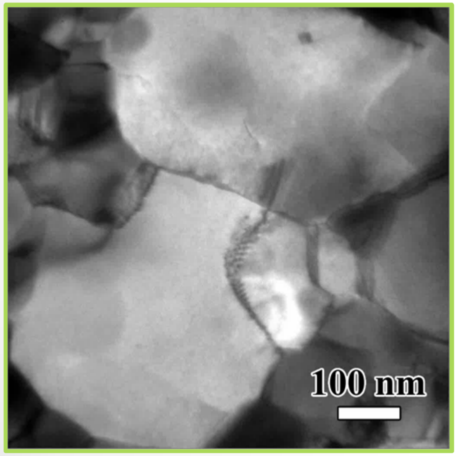
SAND2015-1832C

Ion Beam Modification of Sliding Electrical Contacts and Nanomaterials



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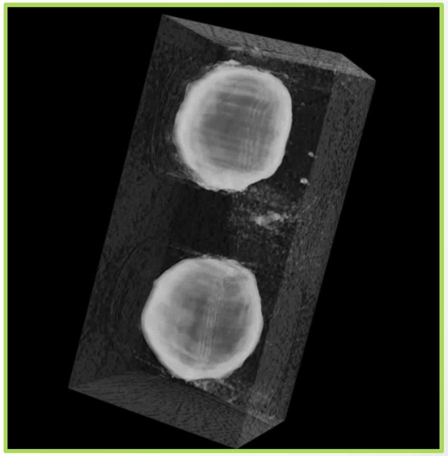
Nanoscale Observations to Implementation



10 April, 2015

Daniel Bufford, Jon-Erik Mogonye, Khalid Hattar, and Somuri Prasad

Sandia National Laboratories, Albuquerque, NM, USA

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Motivation

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- Sliding electrical contacts demand:
  - good conductivity
  - chemical stability
  - wear resistance
- Au meets the conductivity and chemical stability demands, but it lacks wear resistance.

1. Ion beams can modify electrical and mechanical properties.

- Nanoparticle shape and size influences optical properties

2. Ion beams can modify nanoparticles on the nanoscale.

Ion Beam Modification

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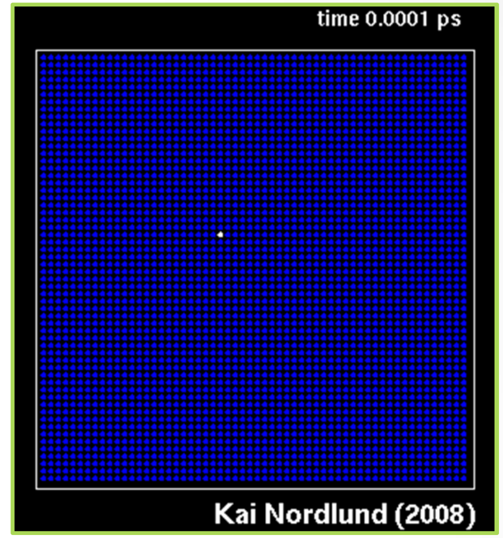
- Energetic ion displaces one or more target atoms
    - Frenkel (vacancy-interstitial) pair
    - Collision cascade
    - Electronic interactions
- Ability to alter microstructure
    - Local reorganization of atoms
    - Defect production
    - Implanted species

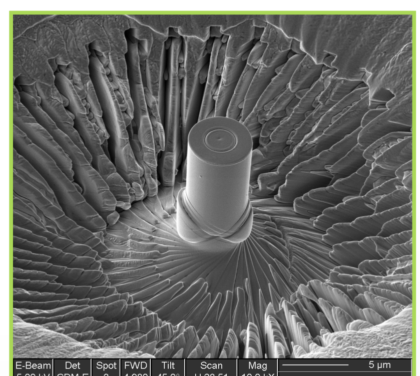


via Wikimedia Commons.

- **Interactions depend strongly on ion mass + energy and target atom mass + bonding.**

Averback, J Nucl Mater, 1994.
Ghaly & Averback, Phys Rev Lett, 1994.
Nordlund & Djurabekova, J Comput Electron, 2014.

- Ions beams may be used for…
    - Semiconductor doping
    - Material removal (FIB milling)
    - Patterning/lithography
    - Analysis (mass spectrometry, ion microscopy)



Nature of Metallic Surfaces

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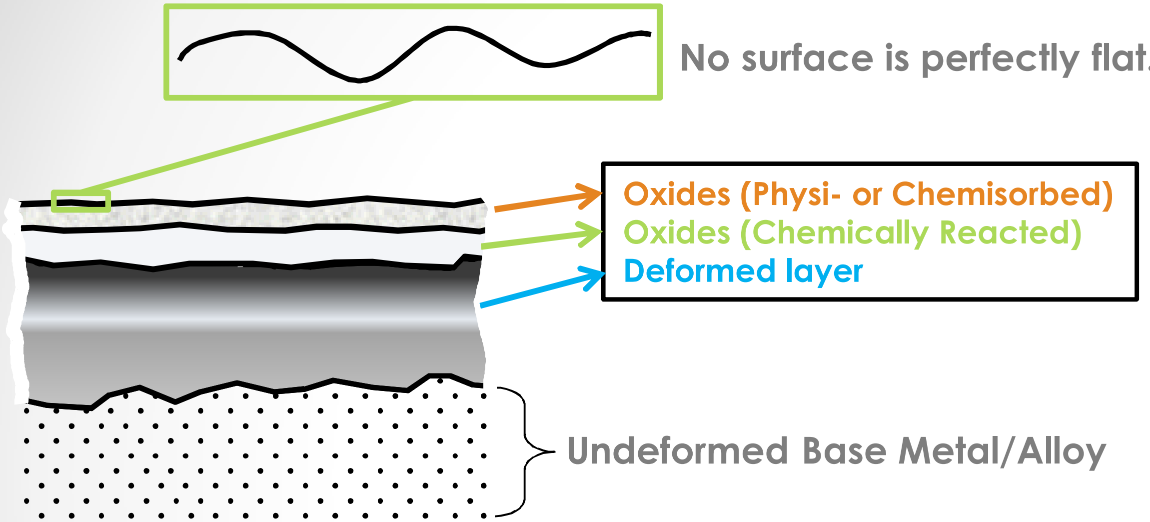
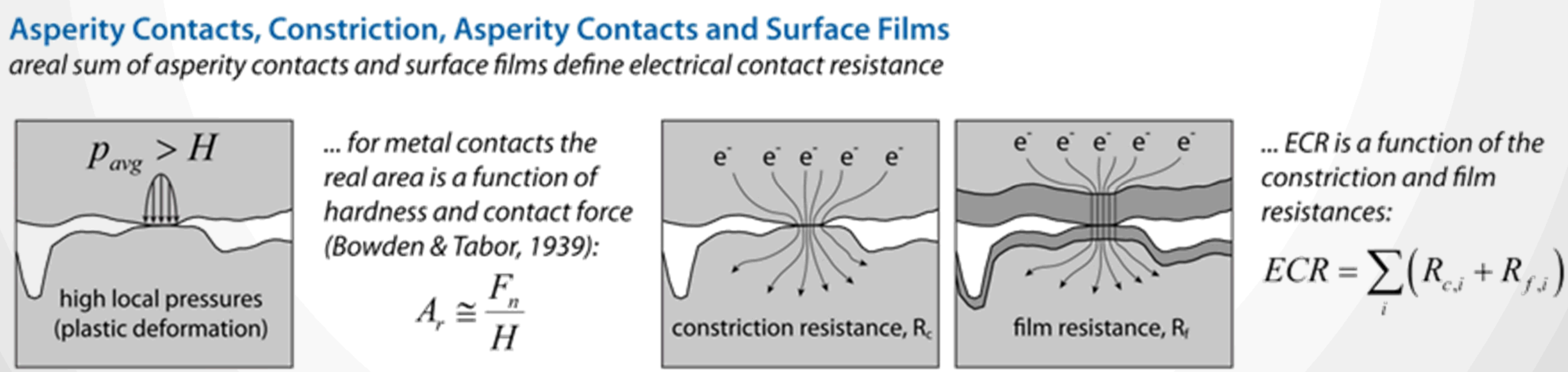


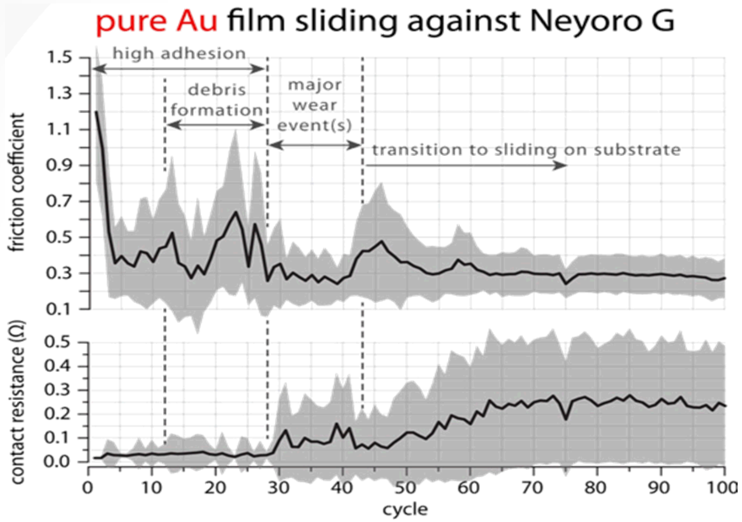
Real area of contact (A_r) to be minimized for low adhesion (Low Adhesive Wear)…

…or maximized for low electrical contact resistance (ECR).



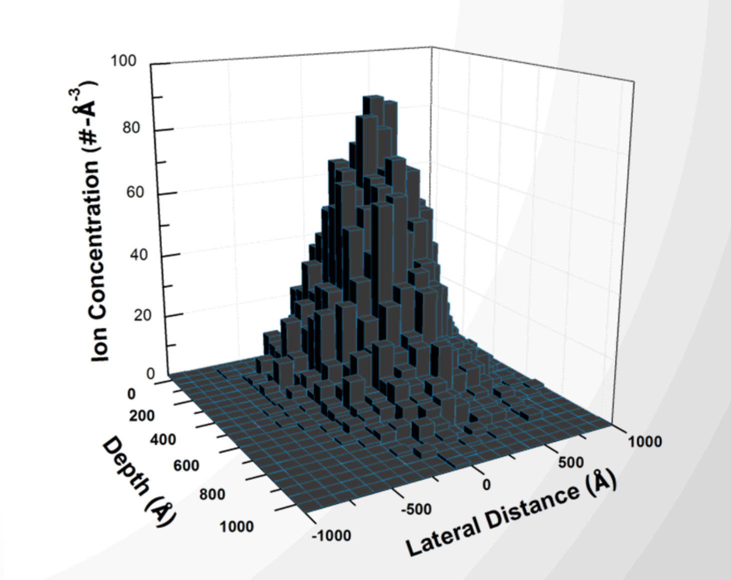
Archard, Journal of Applied Physics (1953) 24:981
R. Holm, Electrical Contacts Handbook (1958) Berlin: Springer-Verlag
Greenwood & Williamson, Proc. Royal Society (1966) A295:300
T.W. Scharf & S.V. Prasad, Journal of Material Science (2013) 48:511-531

Experimental and Modeling Approaches



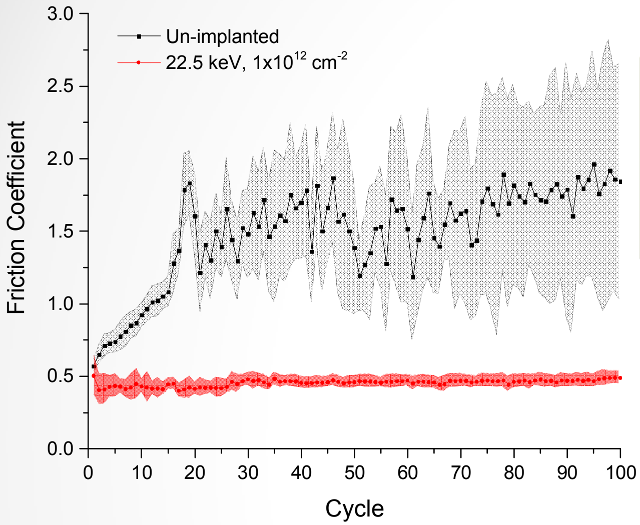
- **ECR-Tribology experiments** with Pure Au
- Neyoro G (Au-Cu), 1/16 in. radius hemispherical tip rider
- Fn = 100 mN (≈290 MPa contact stress)
- 100 Cycles @ v = 1 mm/s
- 1 – 2 mV bias to achieve approximately 100 mA
- Lab air environment at room temperature

- **Simulations**: SRIM 2008 (The Stopping and Range of Ions in Matter, J.F. Ziegler, M.D. Ziegler and J.P. Biersack)
  - Monte-Carlo simulation of kinematic interaction based on empirical data fitted functions
  - Input variables of target material include density, AMU, and thickness.
  - Input variables of ions include AMU, energy, and angle of incidence.
  - Assumes isotropic material, thus no consideration for channeling effects

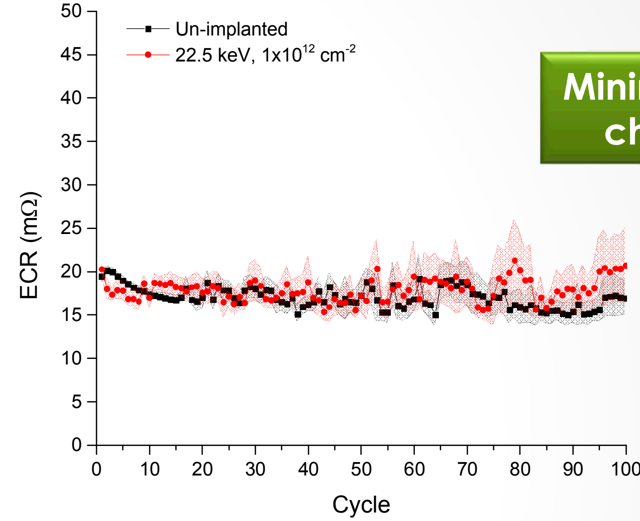


ECR and Wear Measurements

Au implanted @ 22.5 keV to 1 × 10^{12} cm^{-2}



Factor of ~3 Improvement in friction coefficient.

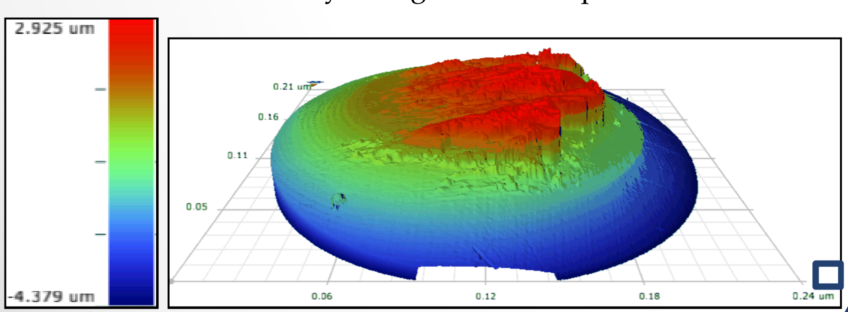


Minimal ECR change

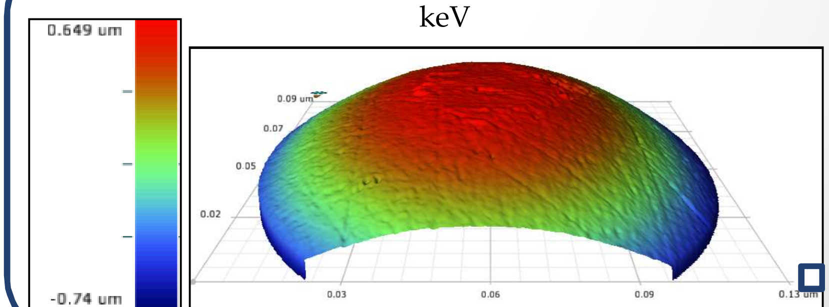
Friction significantly reduced with ^{3}He implantation while maintaining ECR performance.

Scanning white light interferometer topographical construction of riders after 100 cycles:

Rider after 100 cycles against Un-implanted Au



Rider after 100 Cycles against Au implanted to 1E12 cm^{-2} @ 22.5 keV



Wear is significantly reduced with minimal effect to ECR.

Mogonye, *et al*, J Mater Sci, 2015.

STEM Images of Sub-surfaces

Collaborators: P. Kotula

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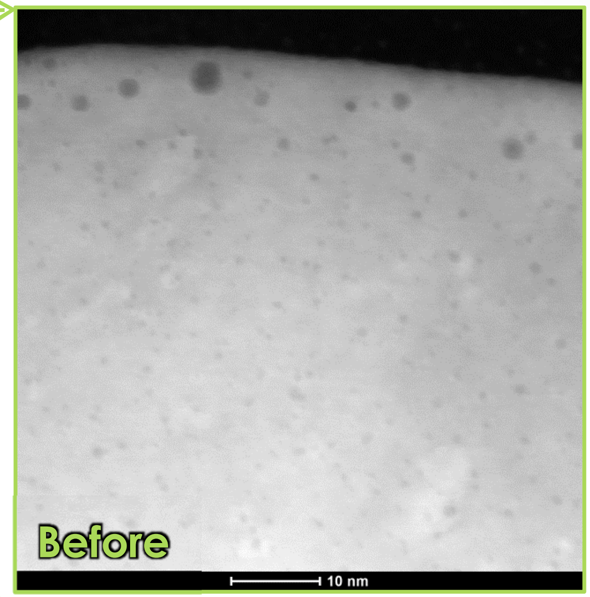
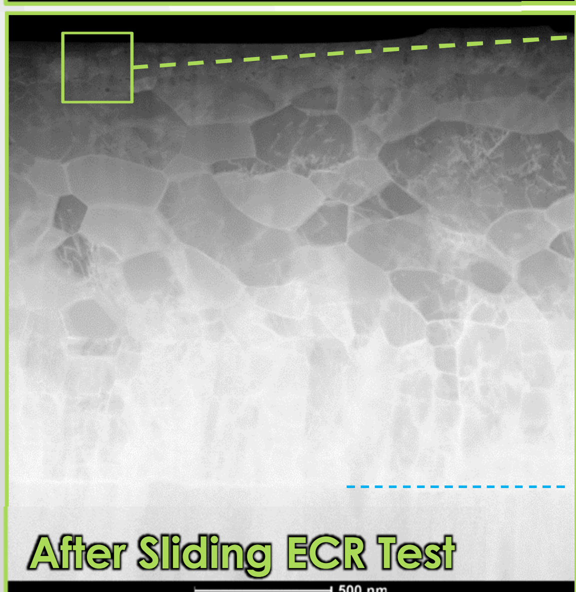
22.5 keV He,
1×10^{12} cm^{-2}

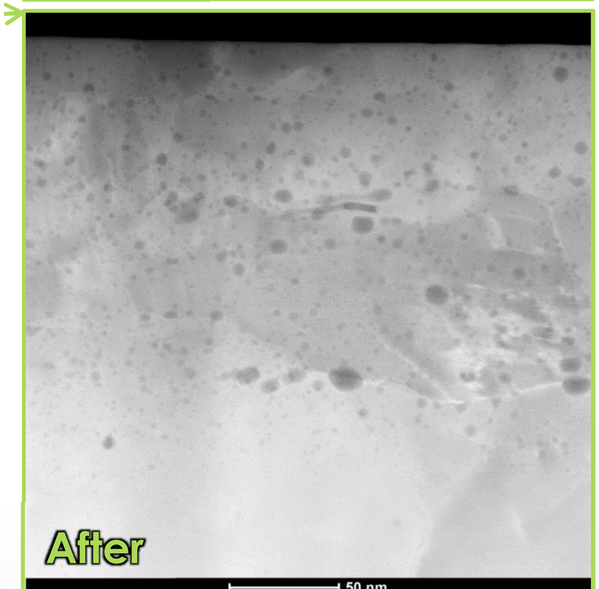
Recrystallization is observable after 100 cycles



He implantation results in small dispersed spherical structures assumed to be He bubbles. Dispersion and depth can be tailored

Au – Pt Interface





An increase in both observable density and diameter of He bubbles, suggests wear induced He coalescence from interstitial and previously unobservable He

Mogonye, *et al*, J Mater Sci, 2015.

Sandia's Concurrent *In situ* Ion Irradiation TEM

Collaborator: D.L. Buller

10 kV Colutron - 200 kV TEM - 6 MV Tandem

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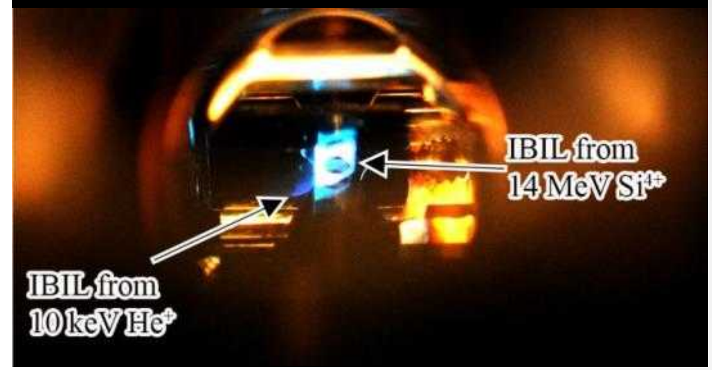
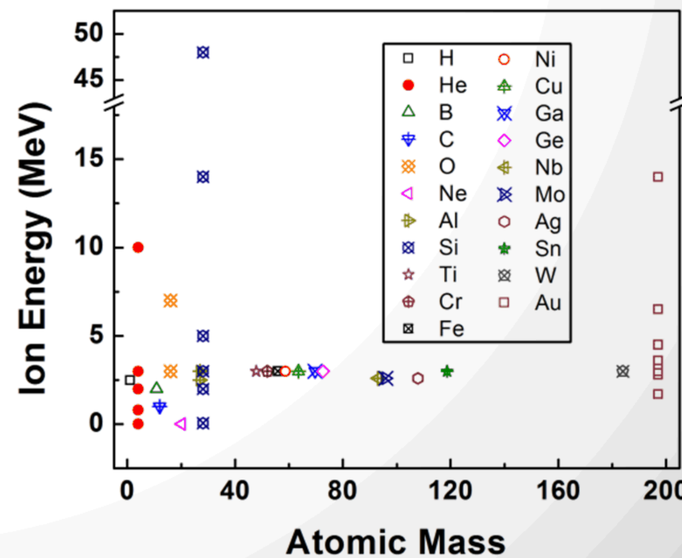
Hattar, *et al*, Nucl Instr Meth Phys Res B, 2014.

IBIL from a quartz stage inside the TEM



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

Ion species & energy introduced into the TEM



TEM: 3.6 MeV Au^{6+}

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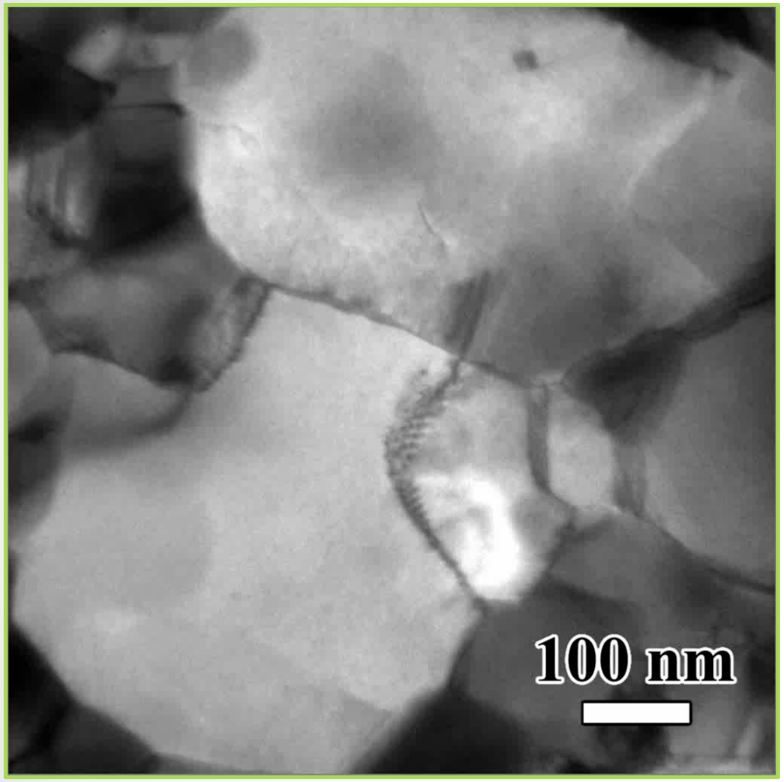
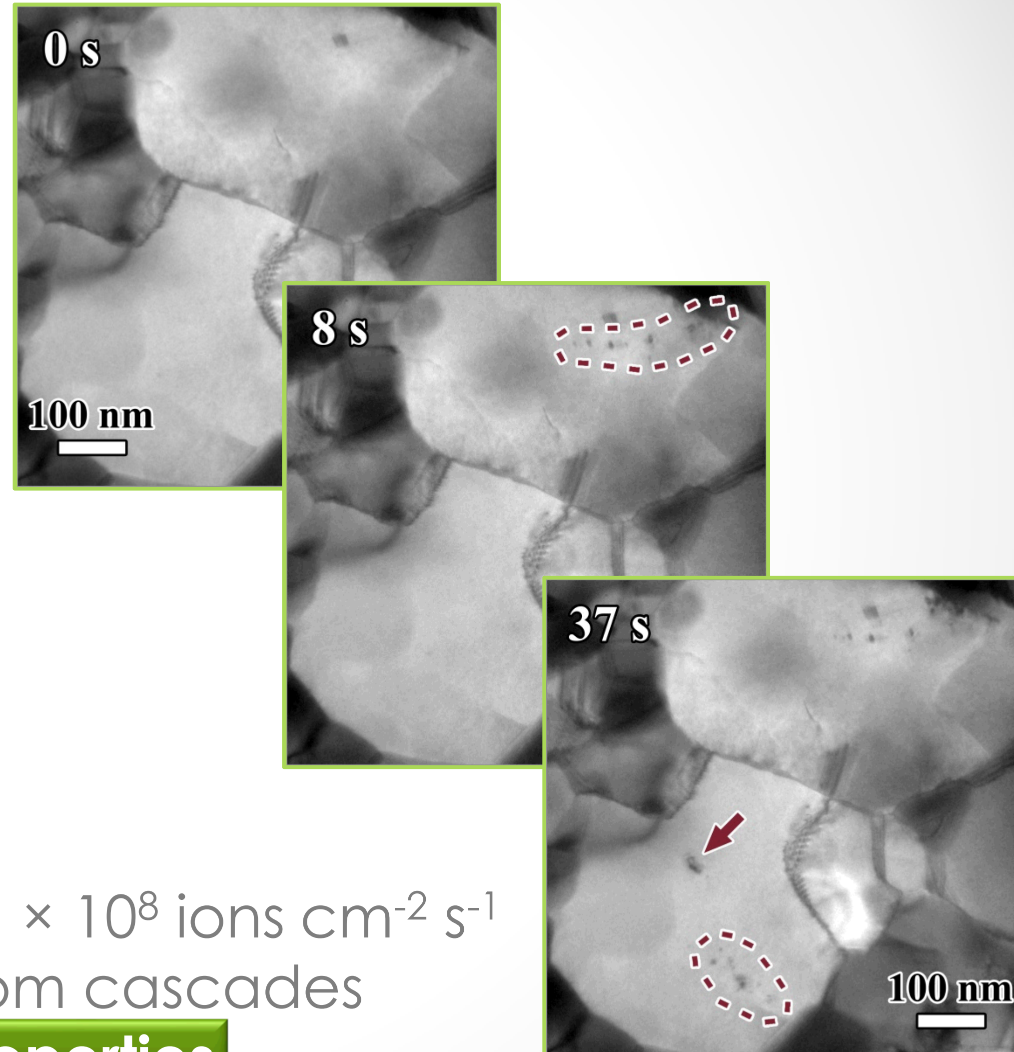
Video playback speed ×5.

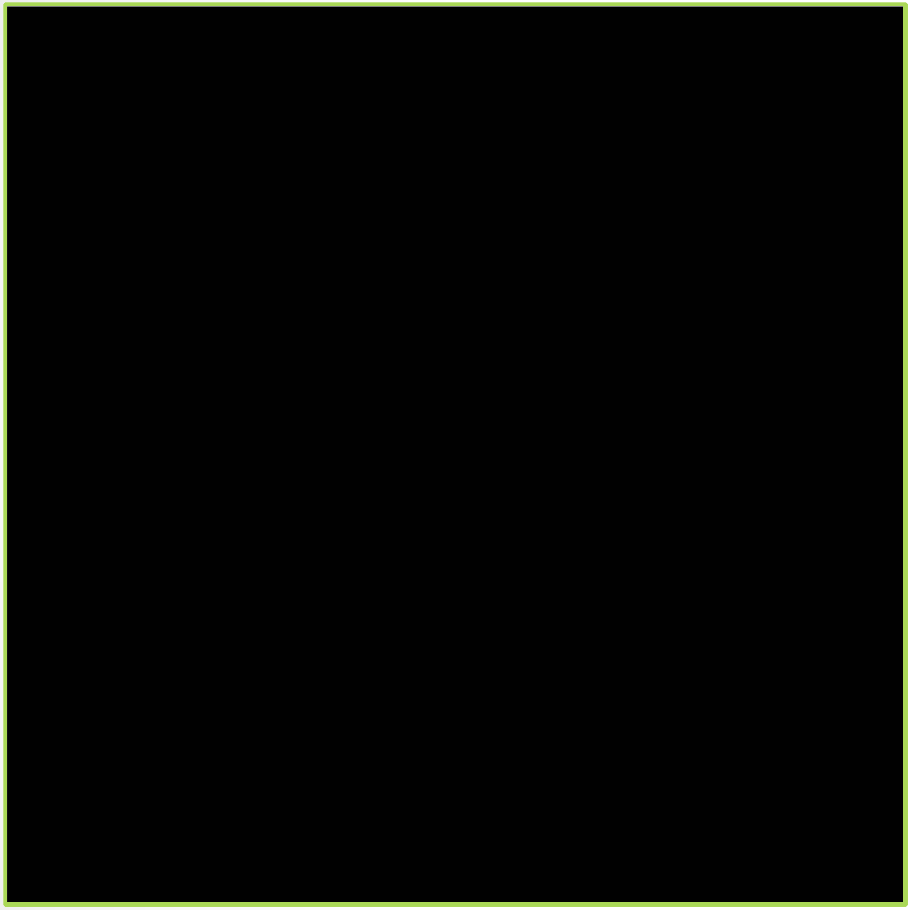


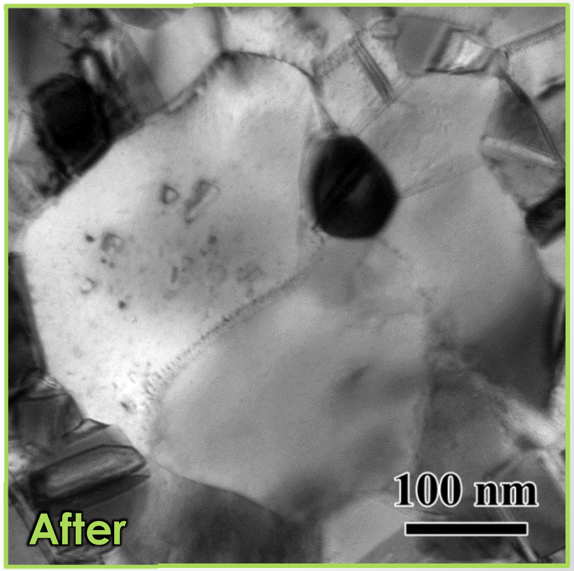


- 3.6 MeV Au^{6+} ions at 2.1×10^{8} ions cm^{-2} s^{-1}
- Large defect clusters from cascades
- **Degradation of wear properties**

Hattar, *et al*, Nucl Instr Meth Phys Res B, 2014.

TEM: 10 keV He^+





- 10 keV He^+ ions at 2.9×10^{13} ions cm^{-2} s^{-1}
- Gradual formation and growth of dislocation loops

Extremes of *In Situ* Implantation

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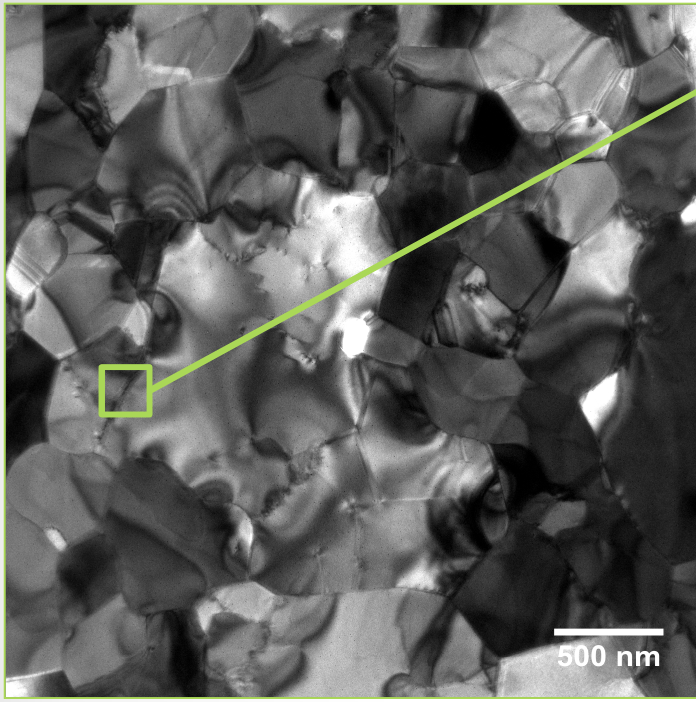
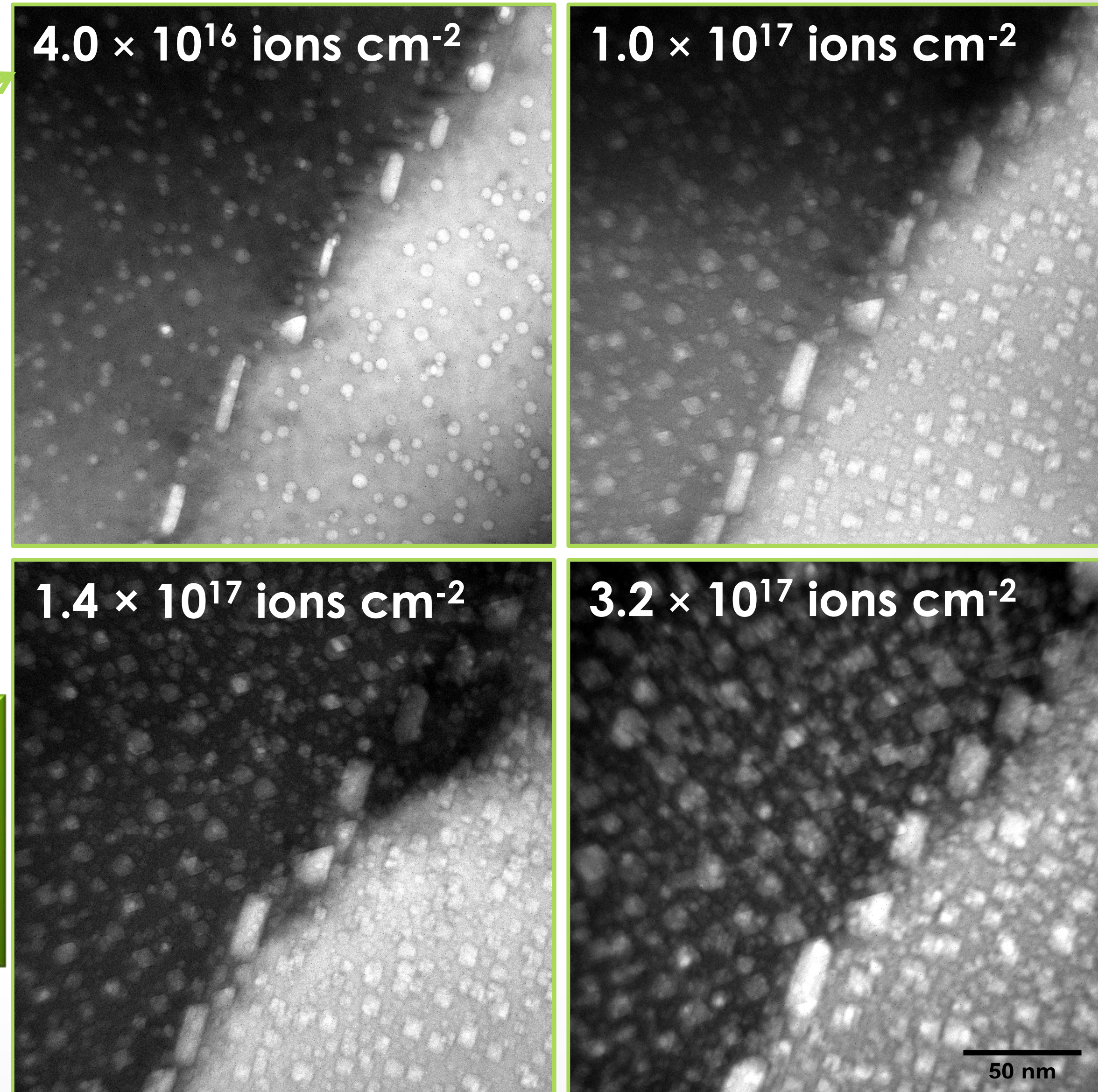
Collaborators: C. Chisholm, P. Hosemann, & A. Minor



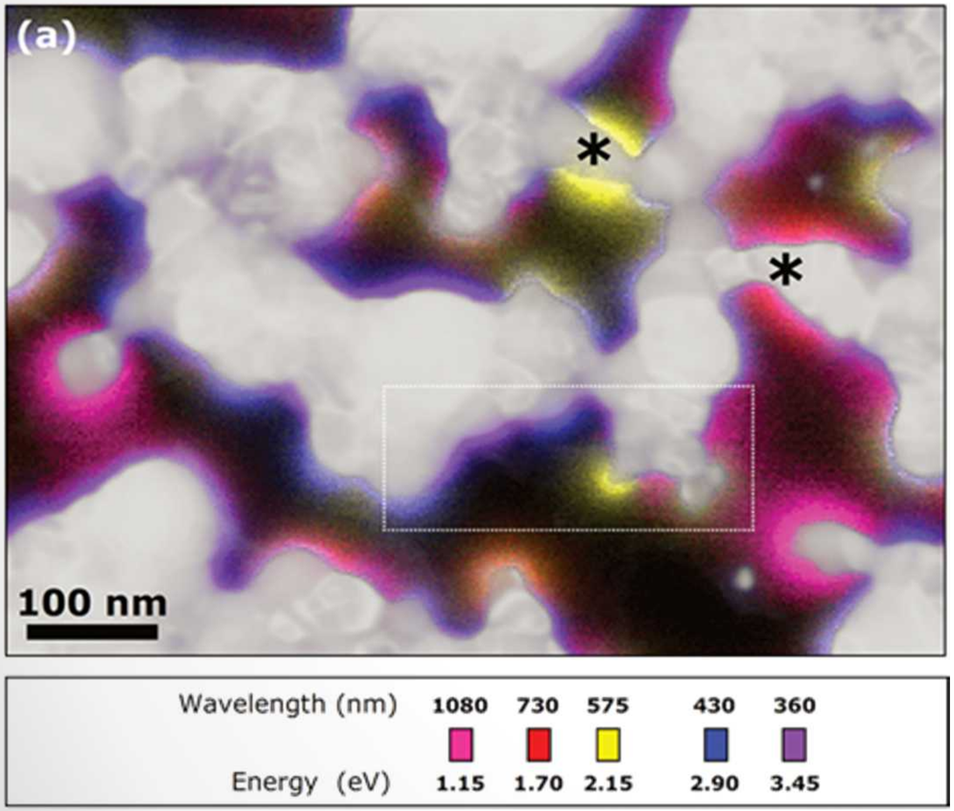


10 keV He^+ into Au TEM foil

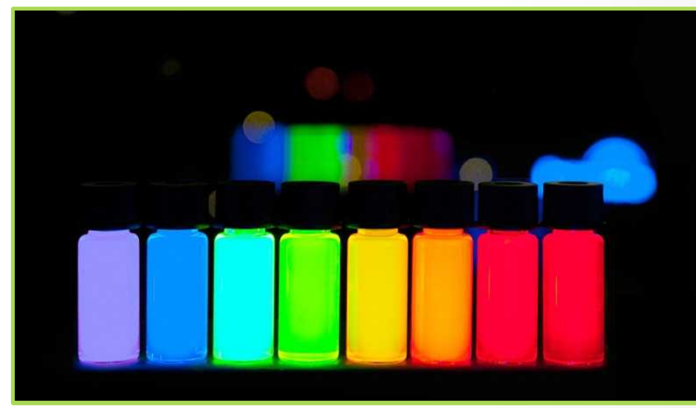
Result: Faceted cavities form a porous microstructure.

Optical properties

Optical properties of nanostructured materials depend sensitively on size and shape.



Bosman, *et al*, Nanotech, 2007.

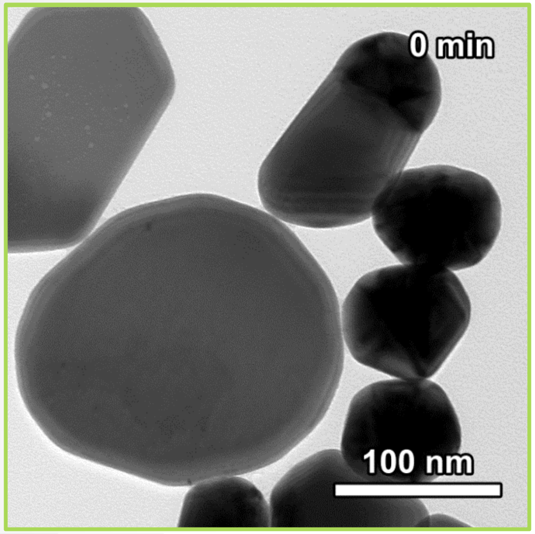


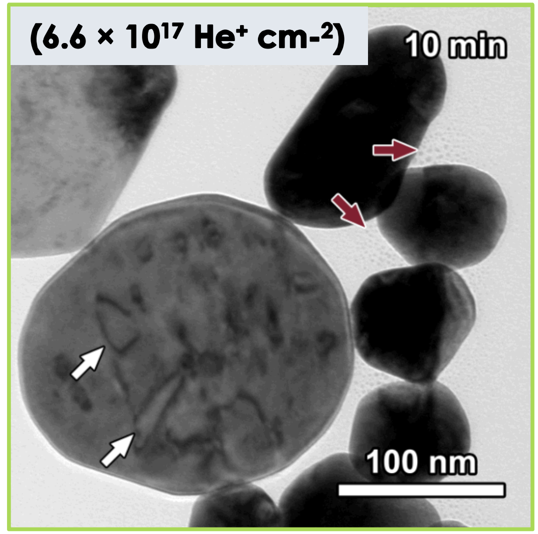
Antipoff, 2012, *via* Wikimedia Commons.

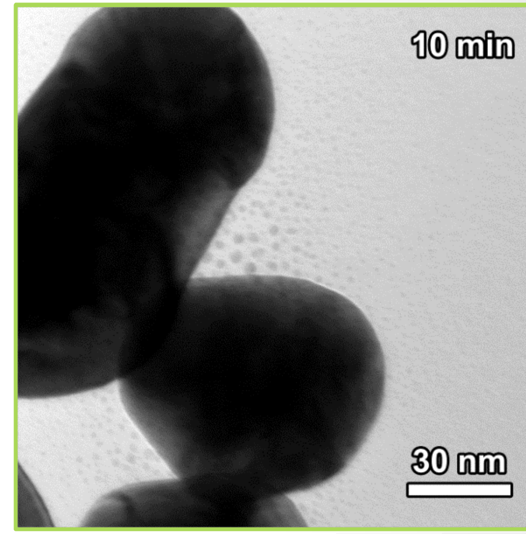
Ion beams can modify these materials in ways not possible by other means.

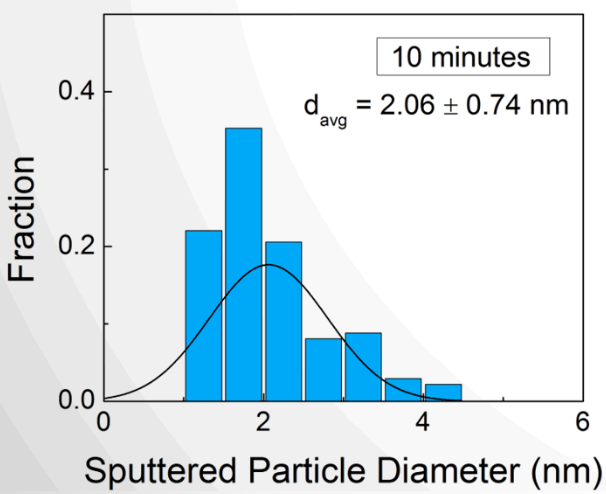
Structural Modification of Nanoparticles by He implantation

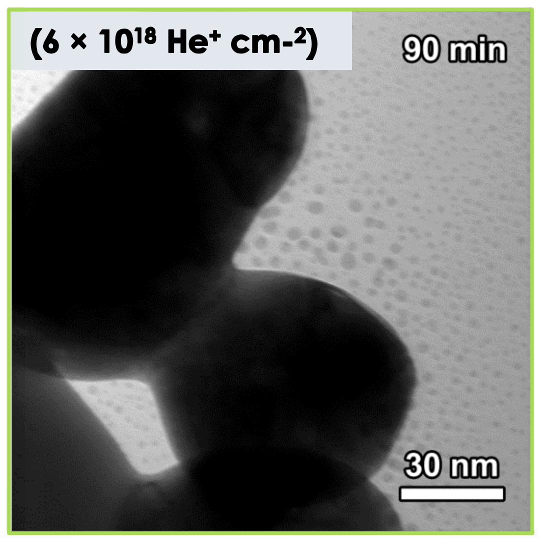
Collaborators: S.H. Pratt & T.J. Boyle

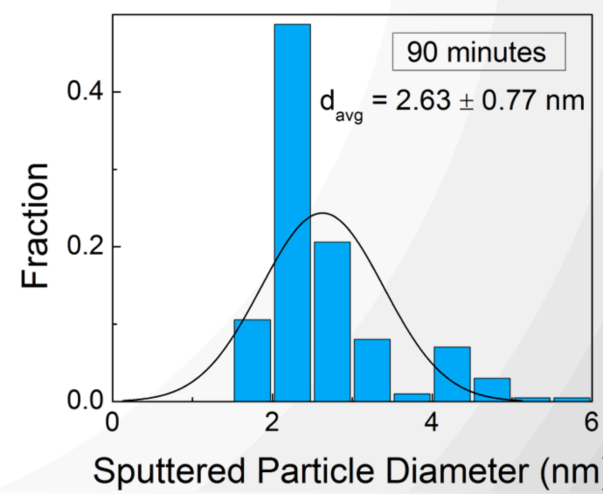






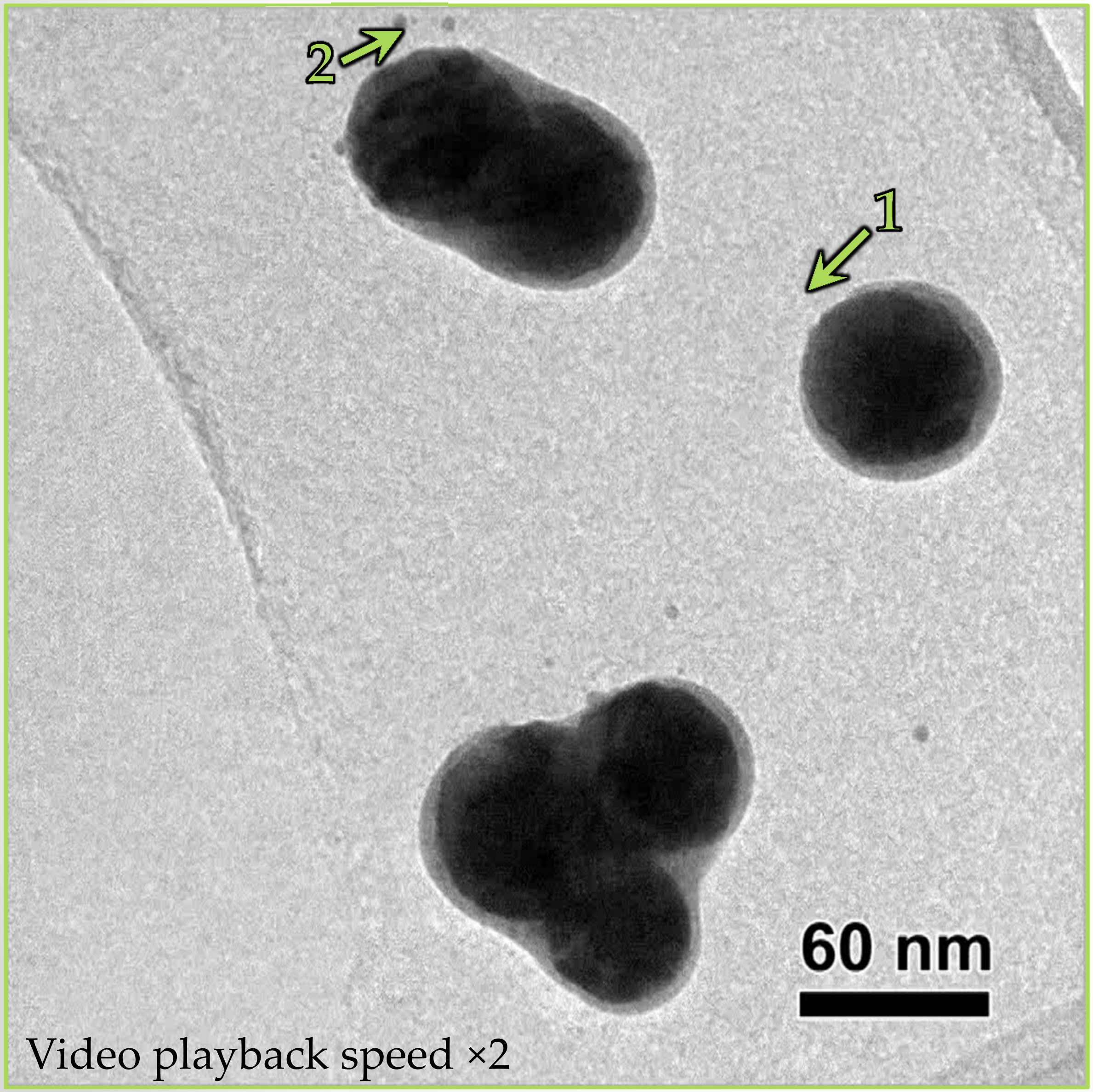






Bufford, *et al*, Chem Commun, 2014.

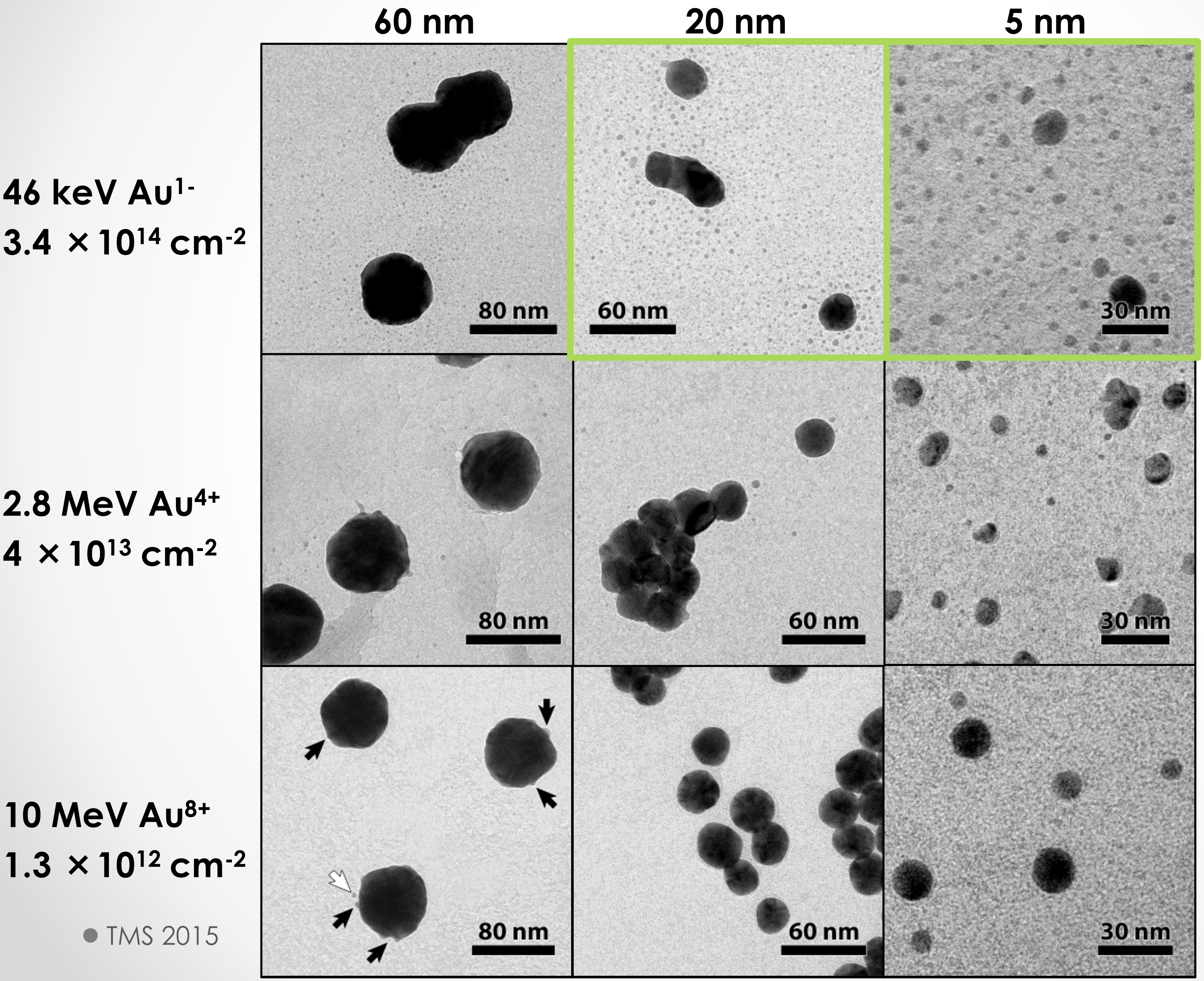
Single Ion Strikes



- 2.8 MeV Au^{4+} ions into 60 nm diameter Au nanoparticles
- 100 kx magnification
- Nanoscale filaments created by individual ions
  - Filaments evolve over time

The permanent and transient structures resulting from single ion strikes can be directly observed.

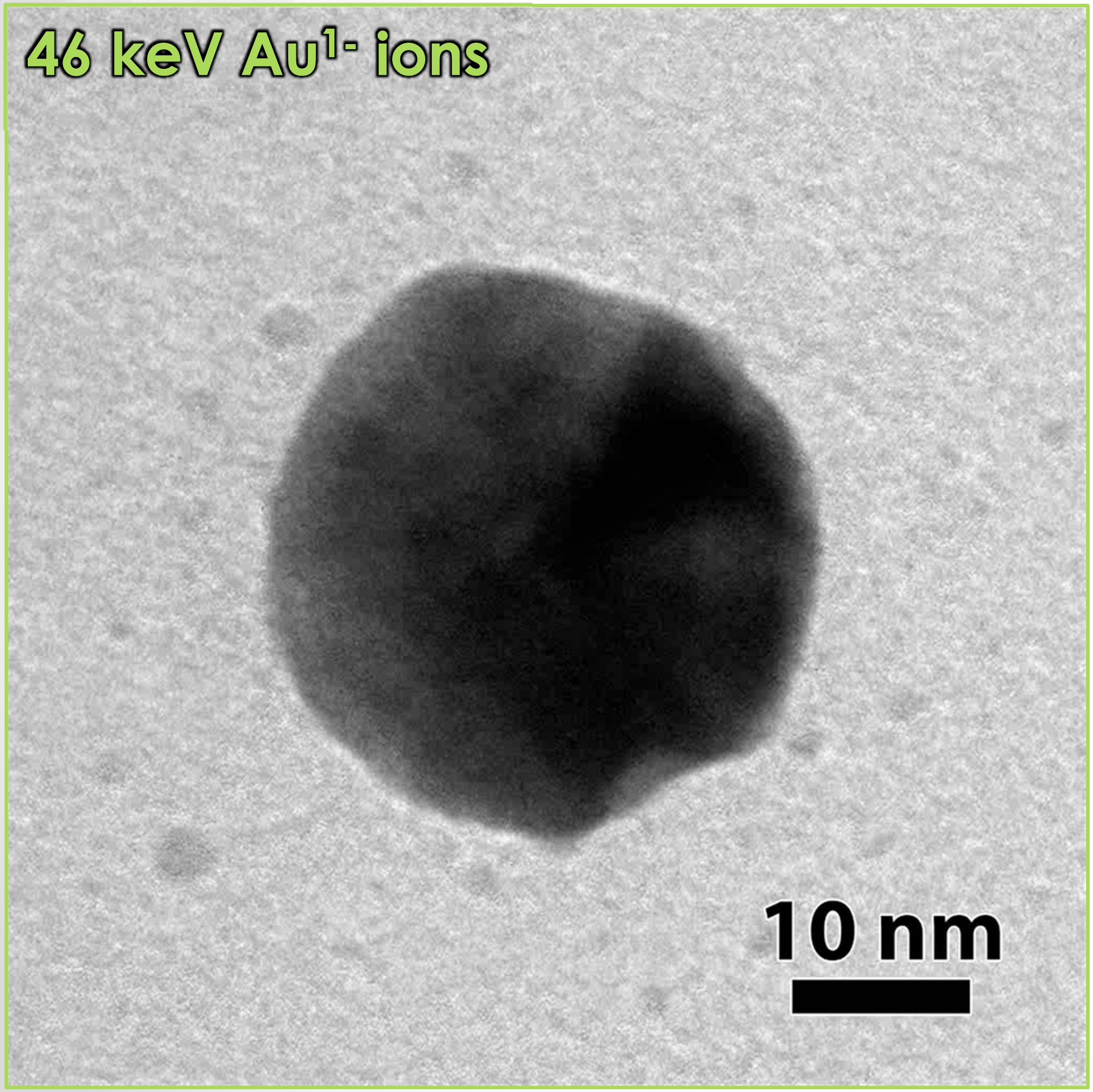
Varying Ion Energy and Au Particle Size

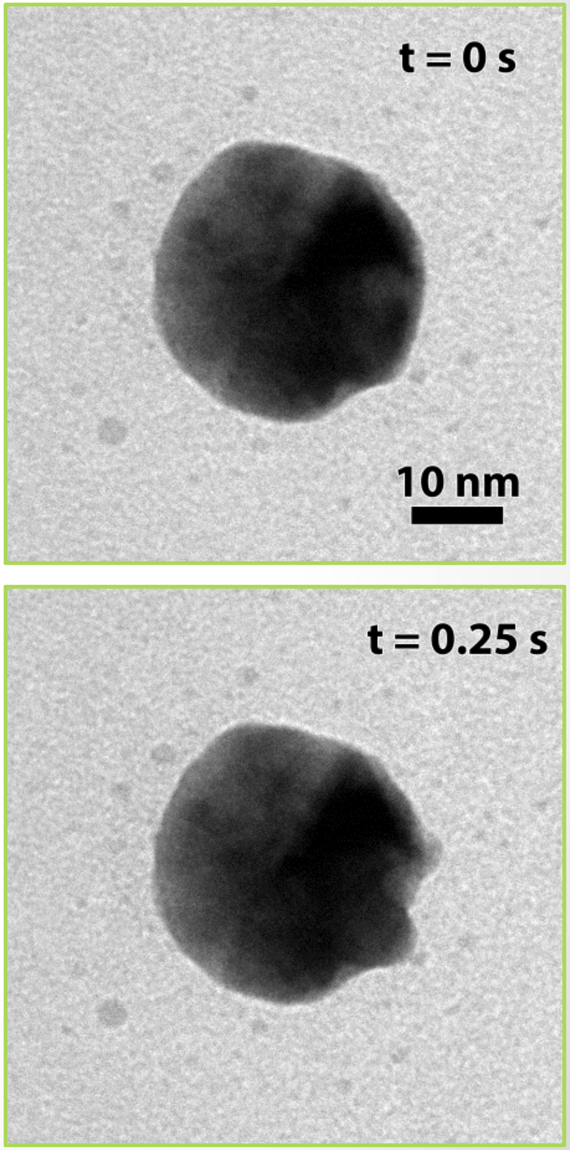


Particle size and ion energy dictate the ratio of sputtering, particle motion, particle agglomeration, and <u>other active mechanisms.</u>

Bufford, *et al*, J Mater Res, 2014.

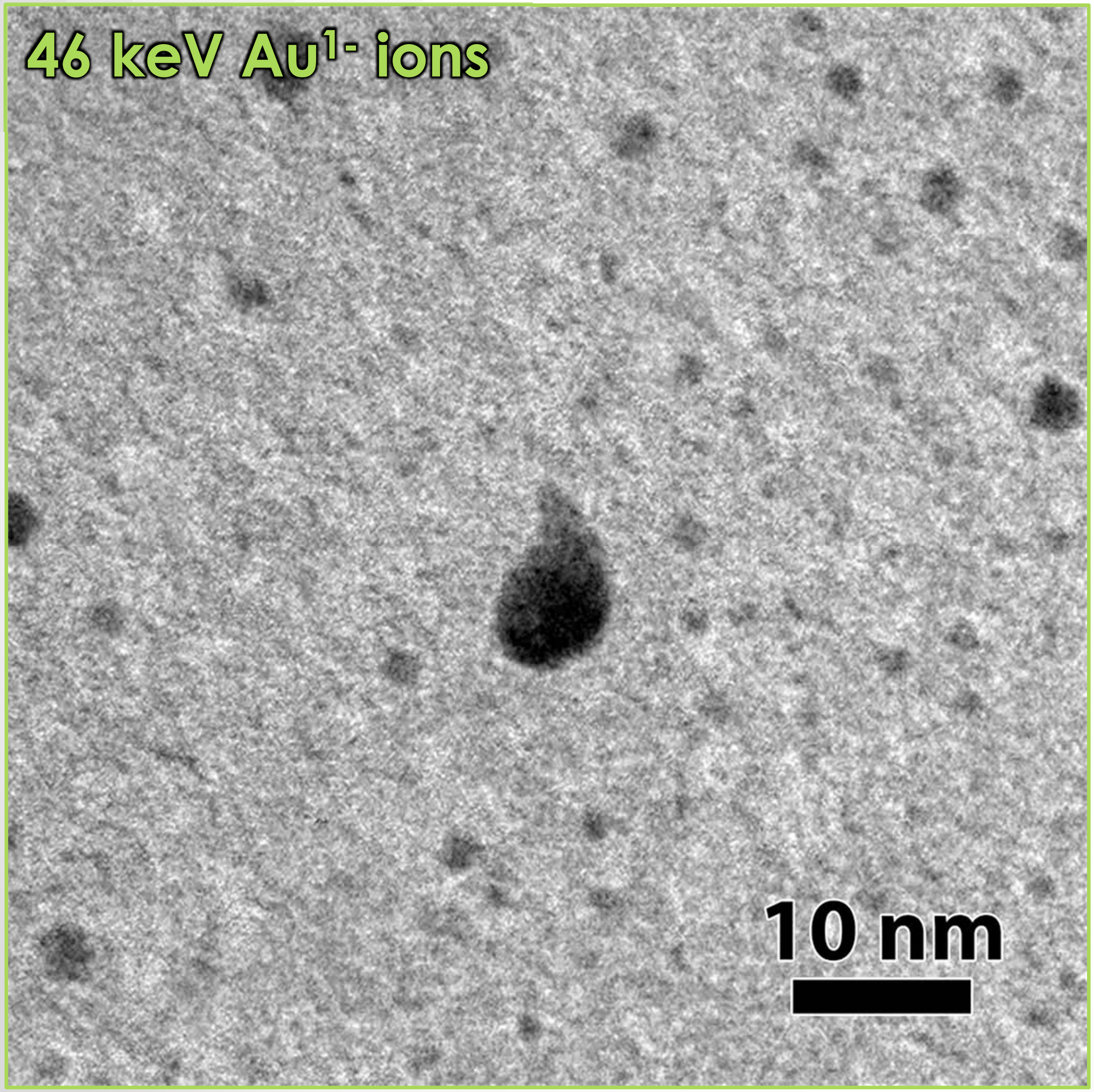
Single Ion Effects: 20 nm

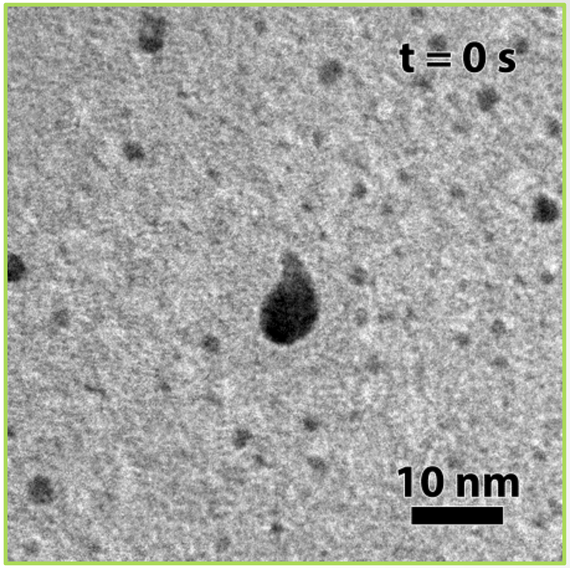


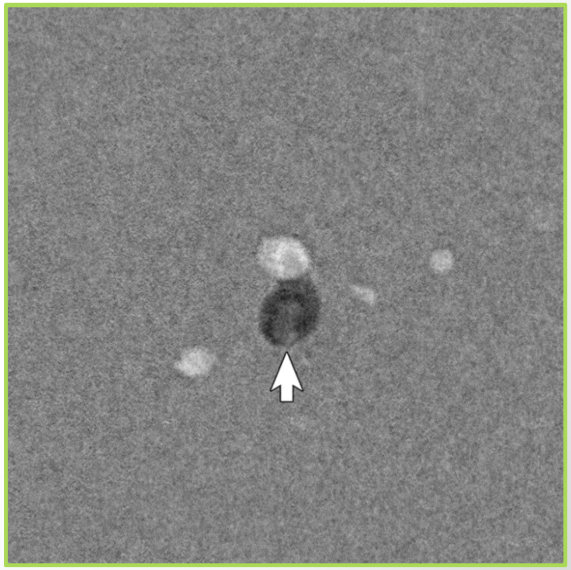


Bufford, *et al*, J Mater Res, 2014.

Single Ion Effects: 5 nm



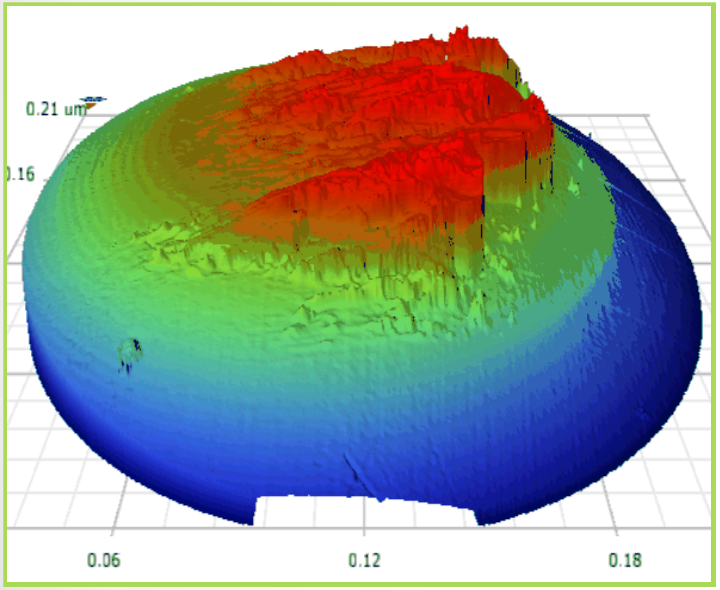


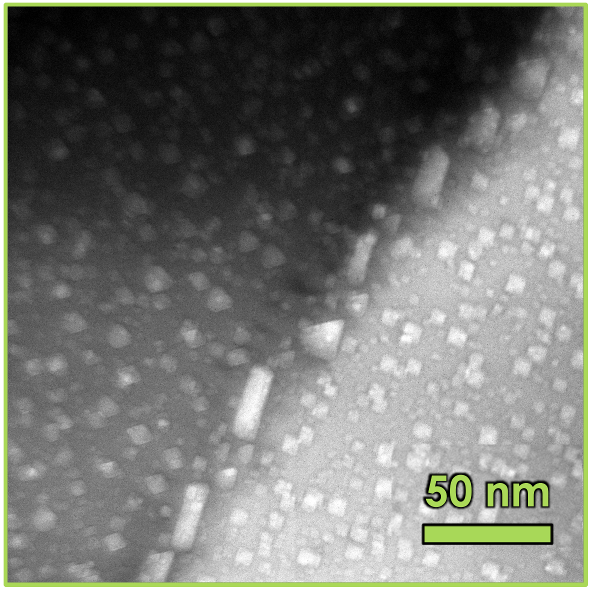


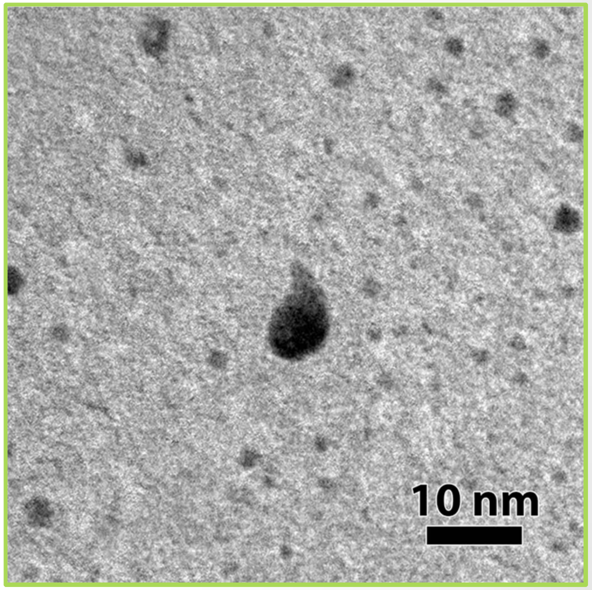
Bufford, *et al*, J Mater Res, 2014.

Summary and Conclusions

- Demonstrated improvement in Au sliding contacts *via* He implantation
- Ion beams may also be used to change shape and size of nanoparticles







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