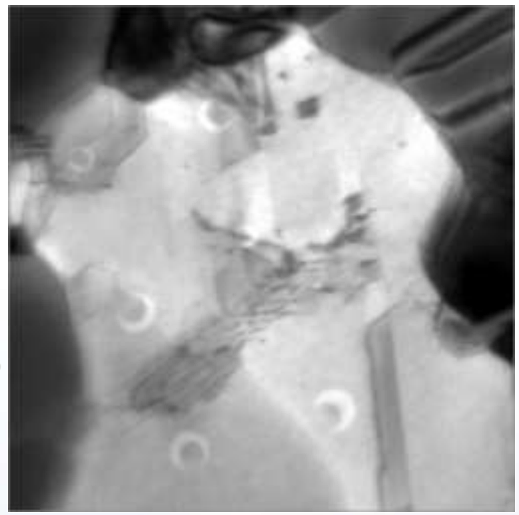
Tailoring the Properties of Metals through Ion Beam Modification

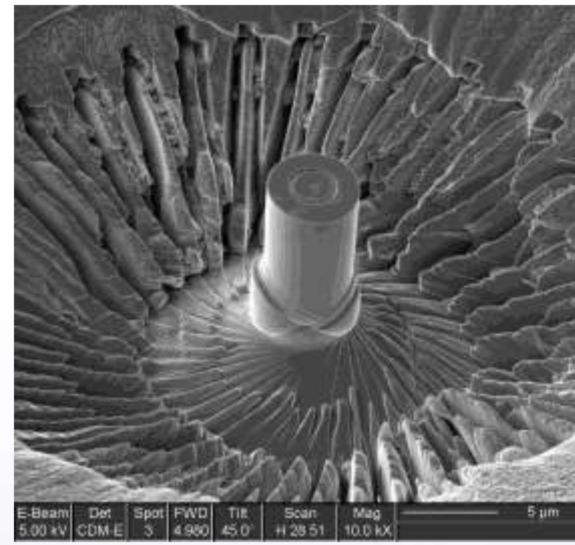
SAND2014-18513C

K. Hattar

Sandia National Laboratories

October 6, 2014





Collaborators:

- **IBL: D. Bufford, D. Buller, S. Pratt, S. Rajasekhara, J. Villone, and all the IBL staff**
- **Sandia: T.E. Buchheit, B. Boyce, T.J. Boyle, F.P. Doty, P. Feng, S. Goods, B.A. Hernandez-Sanchez, A.C. Kilgo, P.G. Kotula, J. Puskar, M.J. Rye, J.A. Scott, P. Yang**
- **External: N. Li, A. Misra, L.N. Brewer, S. Maloy, A. McGinnis, P. Rossi, Protochips Inc.**

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Evolution of Metal Processing

Use the Nearest Stone

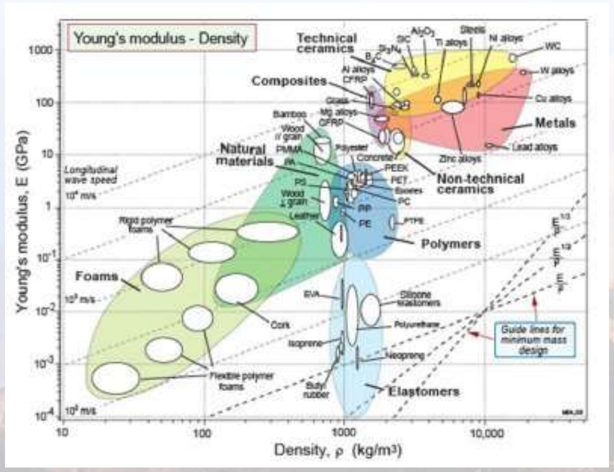
to

- Radar charts and Ashby plots of current material
- Accelerated and field testing
- **Scientist create a new materials. Engineers find an application.**

Materials by Design

- **Physics-based approach**
- **Requires multiscale modeling**
- **Engineers require given properties, Scientists tailor the chemistry and microstructure to achieve it.**

Great vision! We are making strides, but we are not there yet



Micropillar Compression Experiments

Collaborators: M.J. Rye, L.N. Brewer, B. Boyce

Sample Preparation:

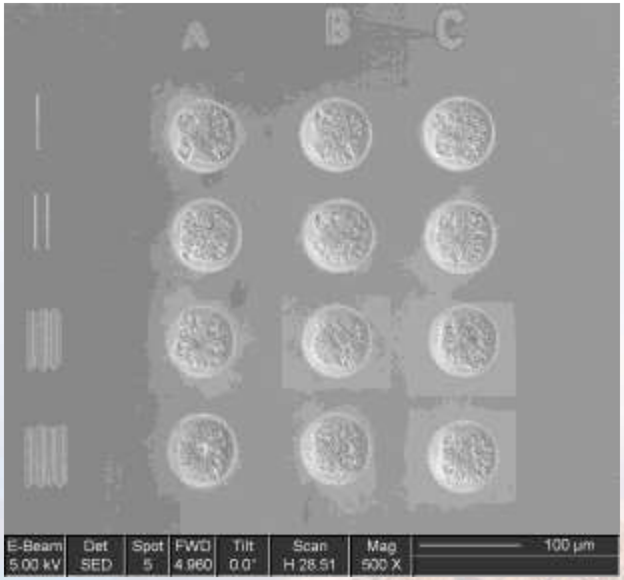
- Copper single crystals (FCC)
- Different crystallographic orientations: (100), (110), and (111)
- Self-ion Implants at 30 MeV to 0 (control), 50 dpa, and 100 dpa.

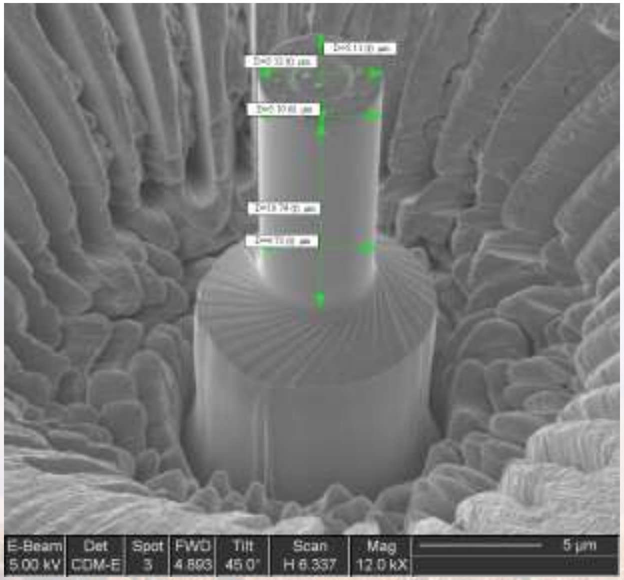
Pillar Manufacturing:

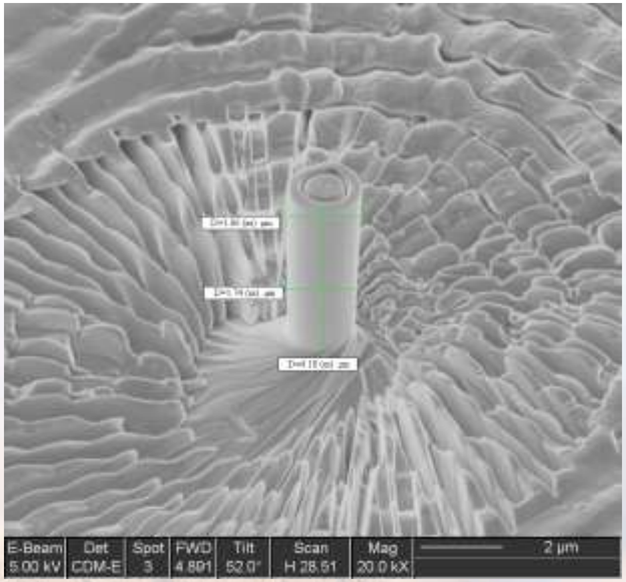
- We employed Uchic's FIB lathe machining process for straight-walled cylinders.
- Array of at least 9 nominally identical pillars tested per condition to assess statistical variability.
- Height varies from 4 µm to 10 µm

Compression Testing:

- Hysitron Performech Nanoindenter permits <1 nm and <1 µN resolution.
- 25 µm flat ended cone indenter in feedback displacement control, rather than typical force control.
- Pillars compressed 10% strain at a strain rate of 0.025 s^{-1}.







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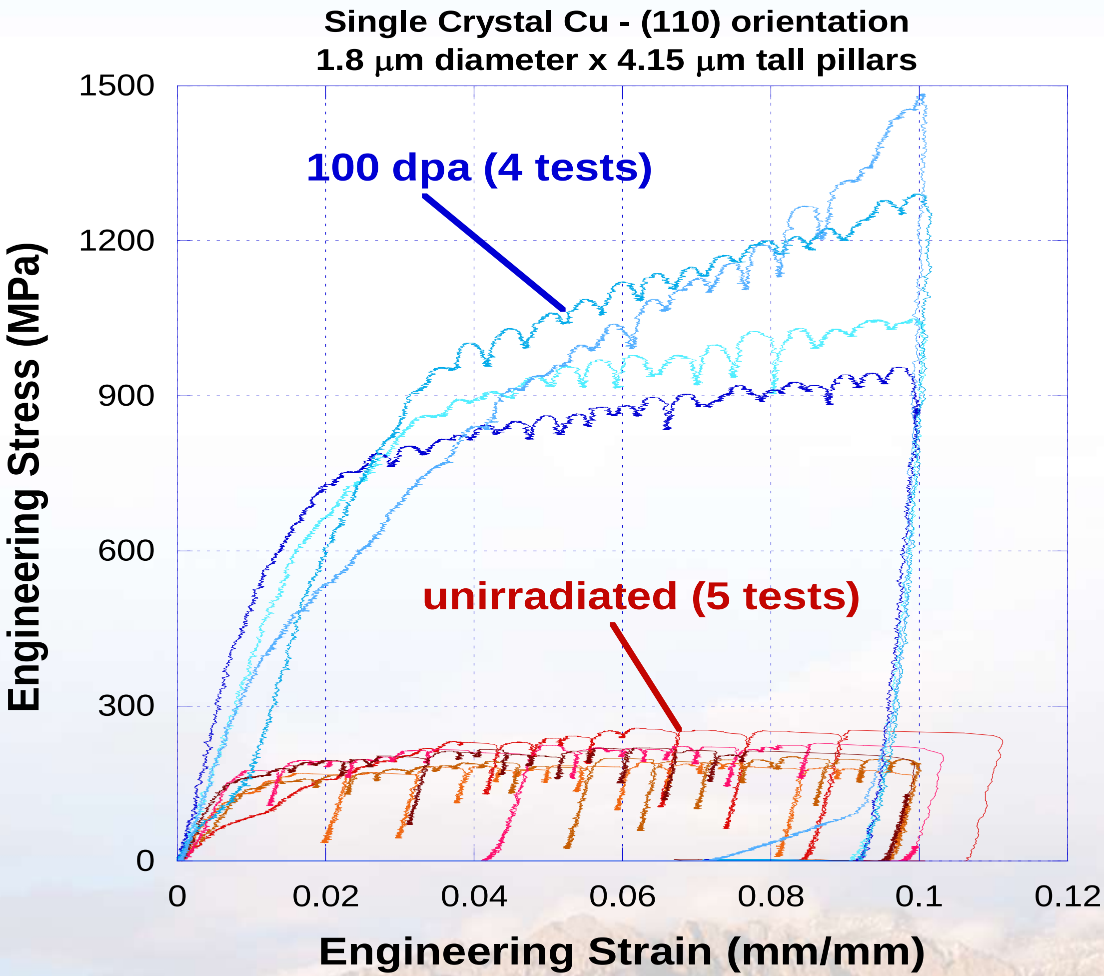
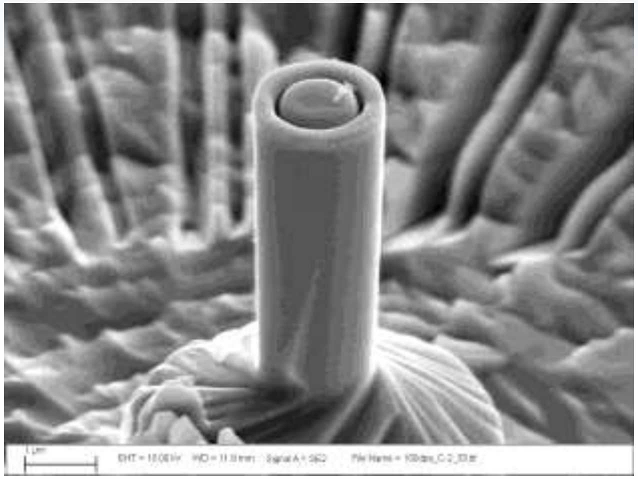
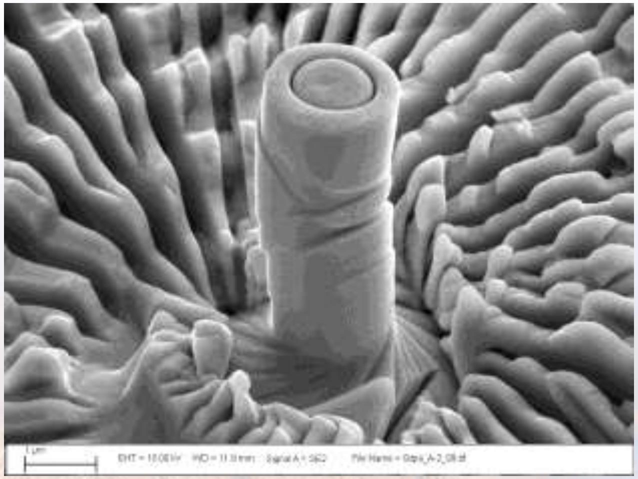
Small Micropillar Compression

Collaborators: M.J. Rye, L.N. Brewer, B. Boyce





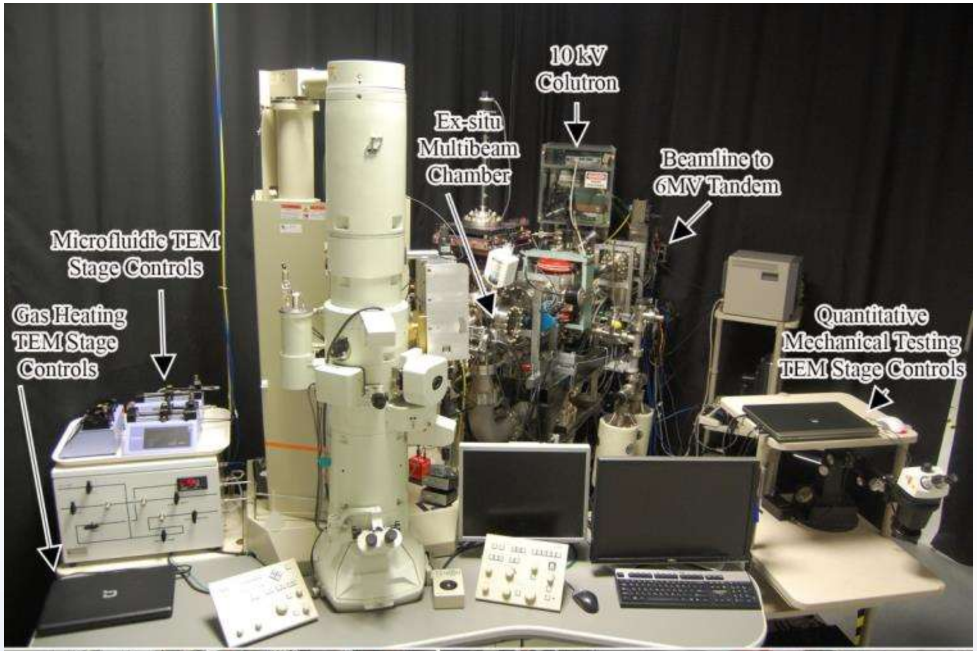


This indicates that the 4 μm-tall pillars are 5 times stronger and show no signs of slip band formation. However, predictive physics-based modeling requires deeper understanding

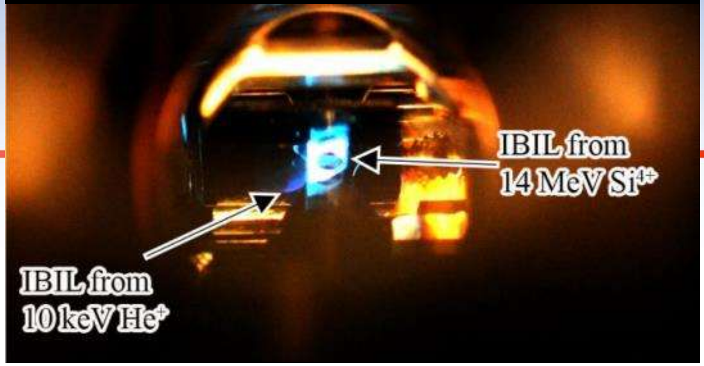
Sandia's Concurrent *In situ* Ion Irradiation TEM Facility

Collaborator: D.L. Buller

10 kV Colutron - 200 kV TEM - 6 MV Tandem

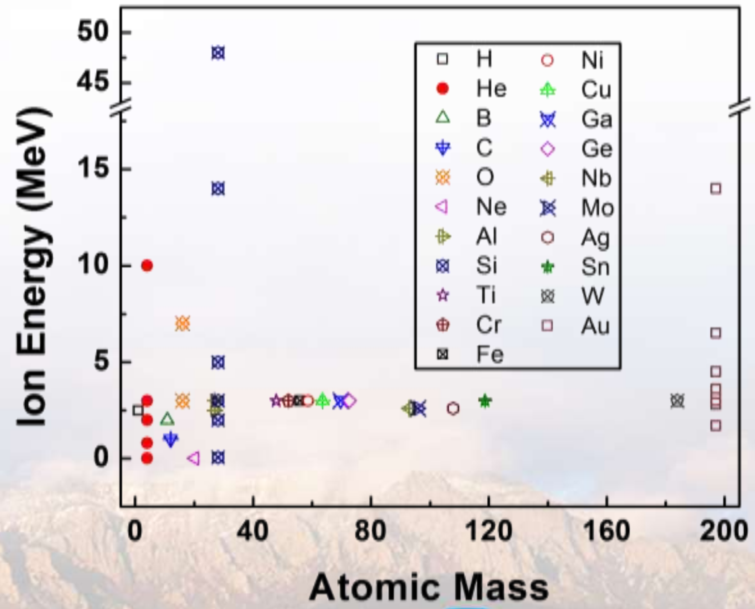


IBIL from a quartz stage inside the TEM



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

Ion species & energy introduced into the TEM



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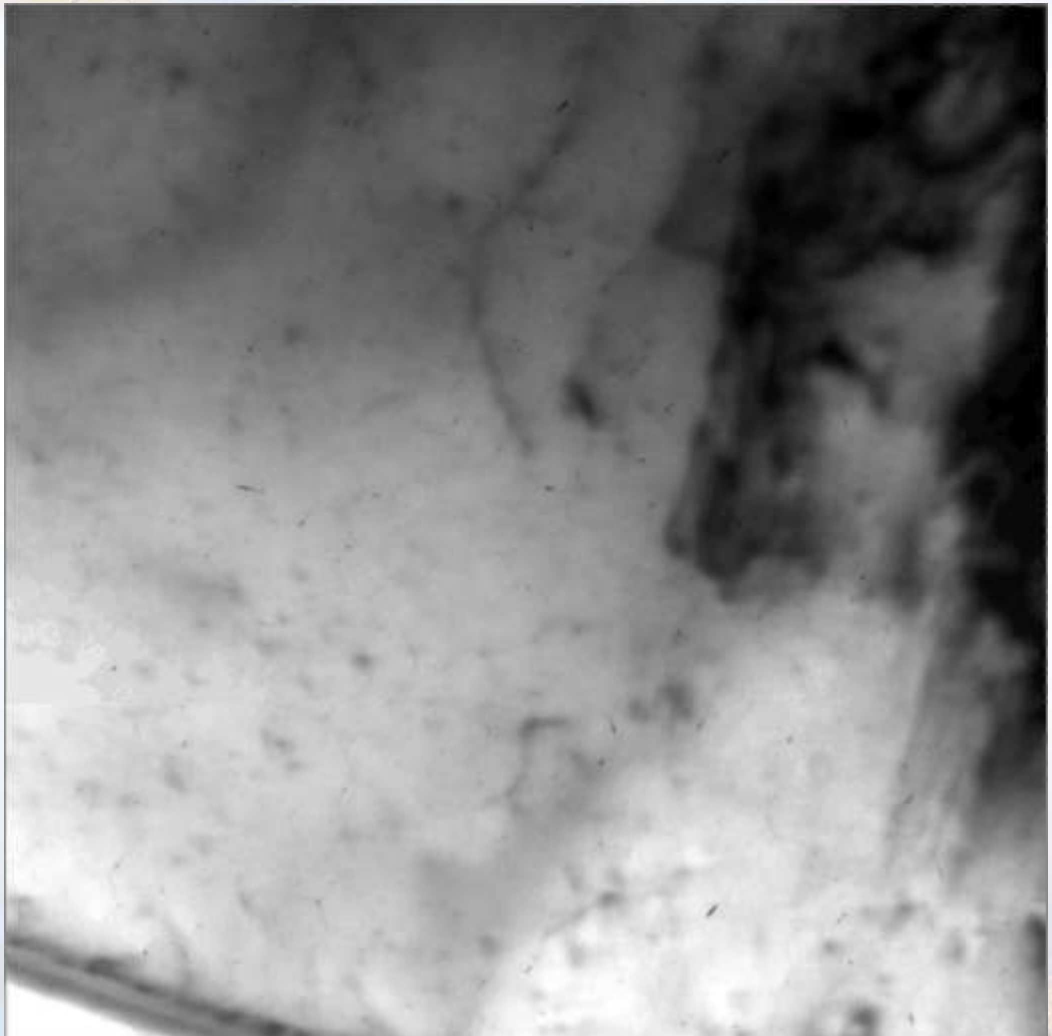
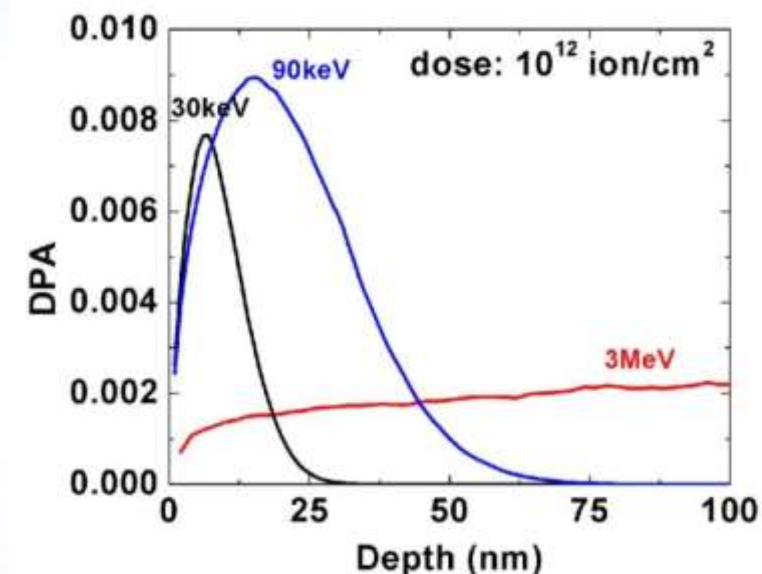
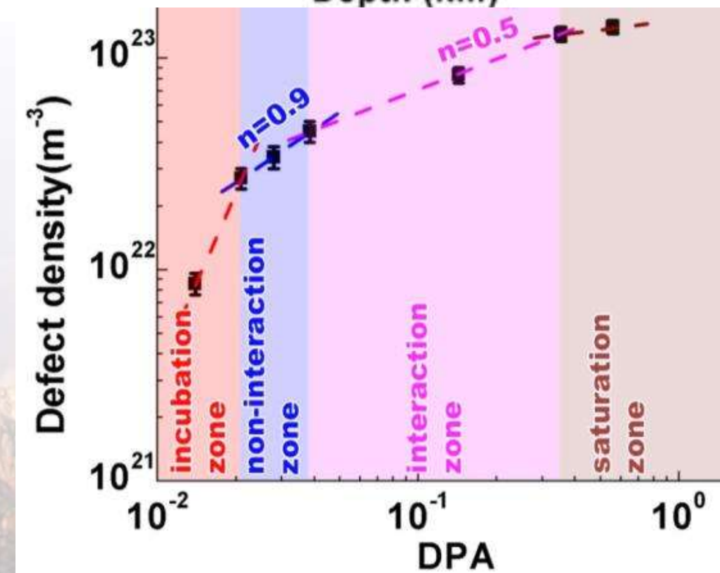
Quantifying Defect Evolution in Irradiated Cu

Collaborators: N. Li & A. Misra

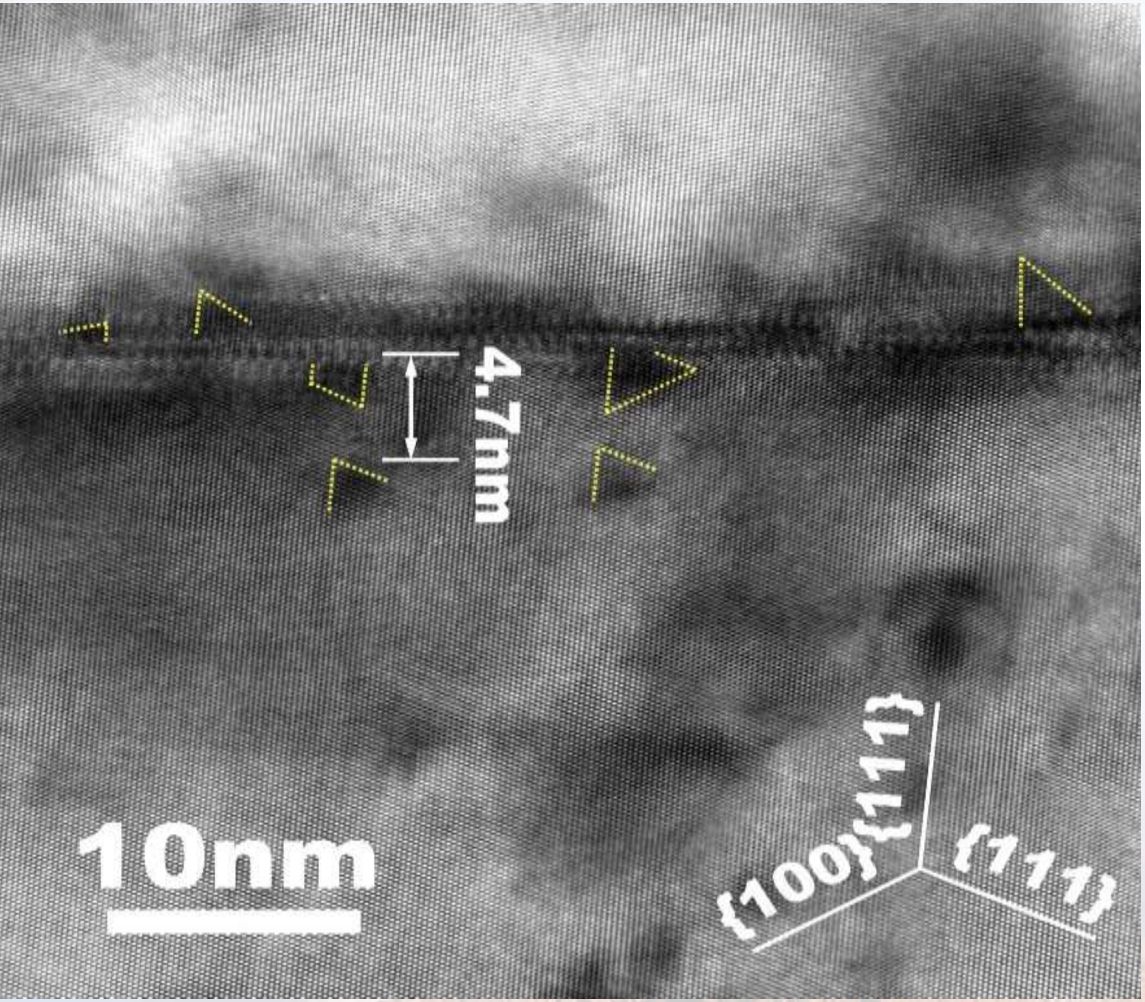


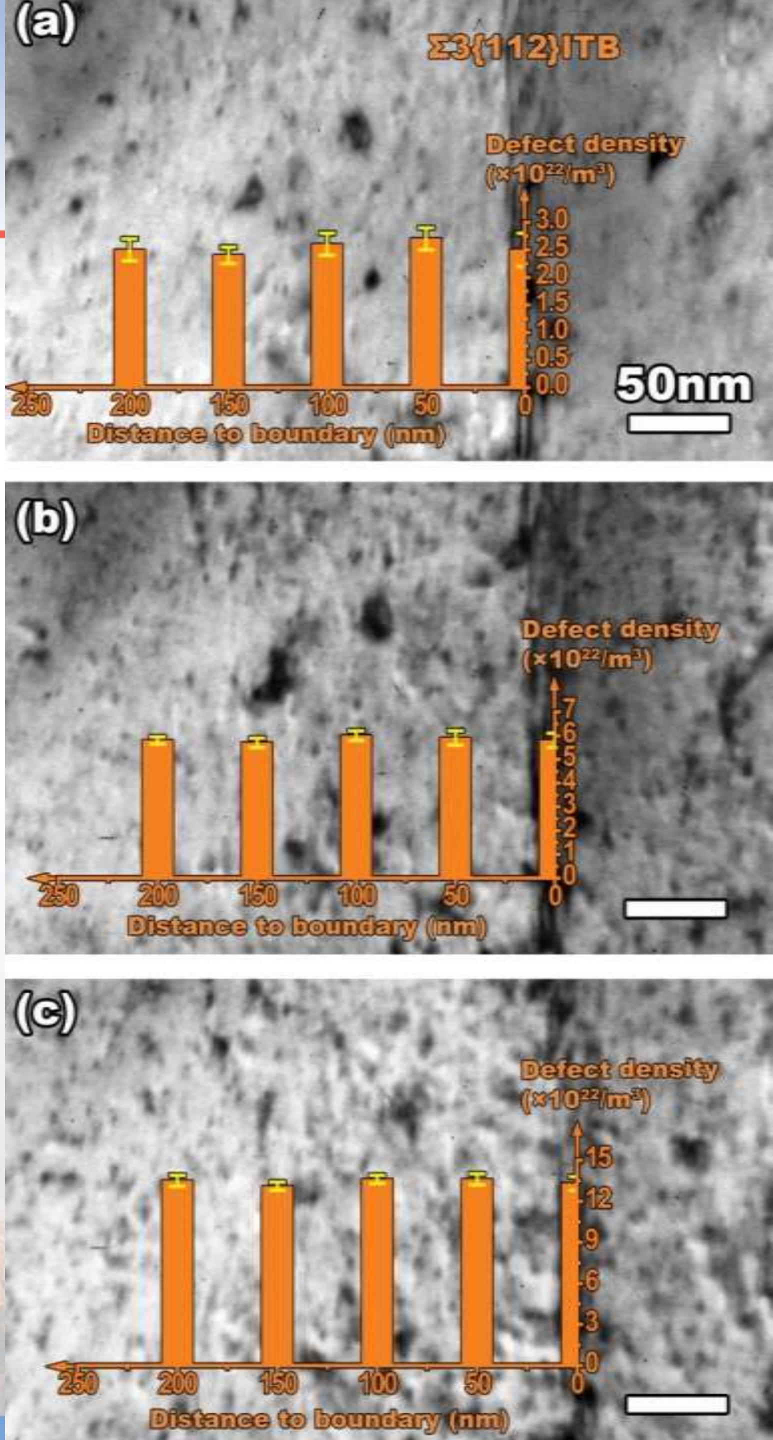




Defects are Altered Little by the Presence of Grain Boundaries

Collaborators: N. Li & A. Misra

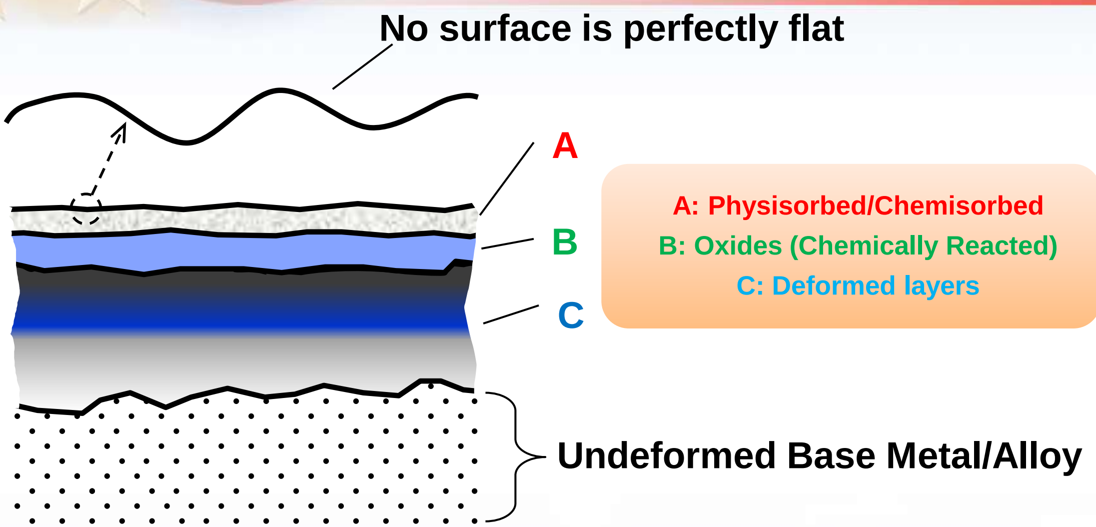




SFT appear to be directly at GB

No change in defect density is observed near GB

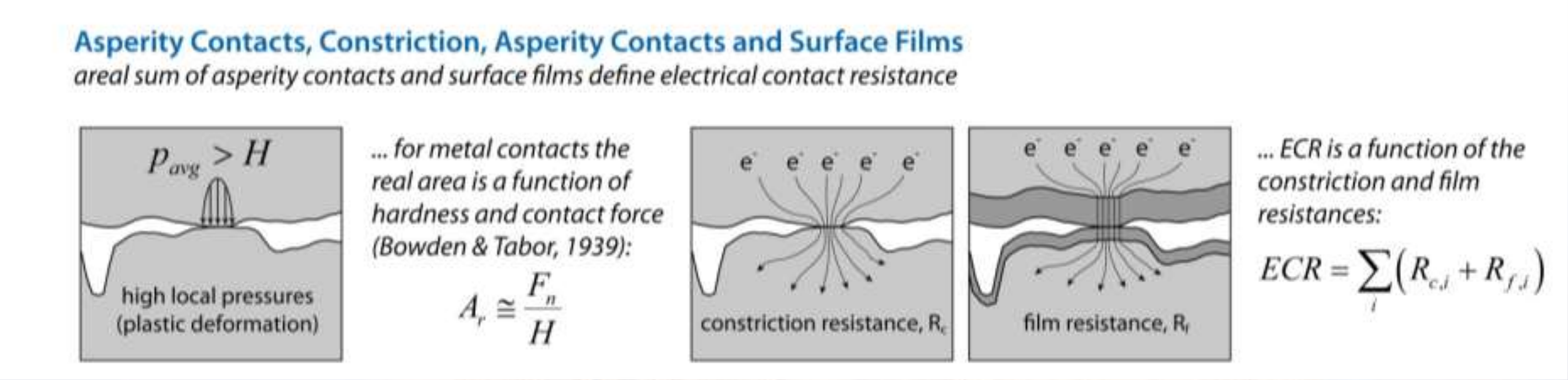
Tailoring Wear Properties in Au Sliding Contacts



Real area of contact (A_r) to be minimized for low adhesion

(Low Adhesive Wear)

Or maximized for reduced 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

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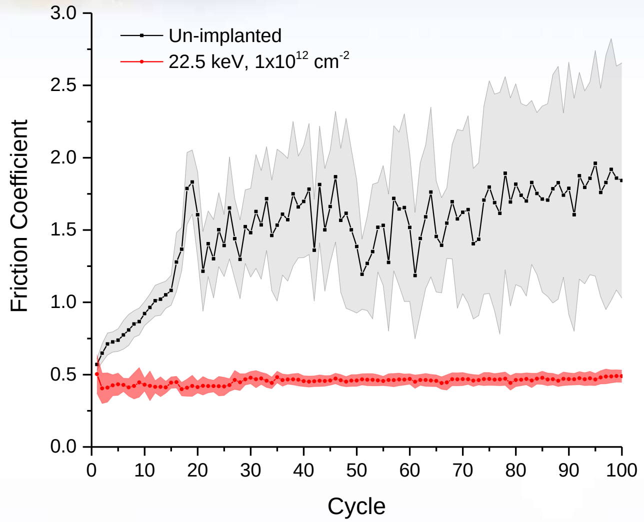
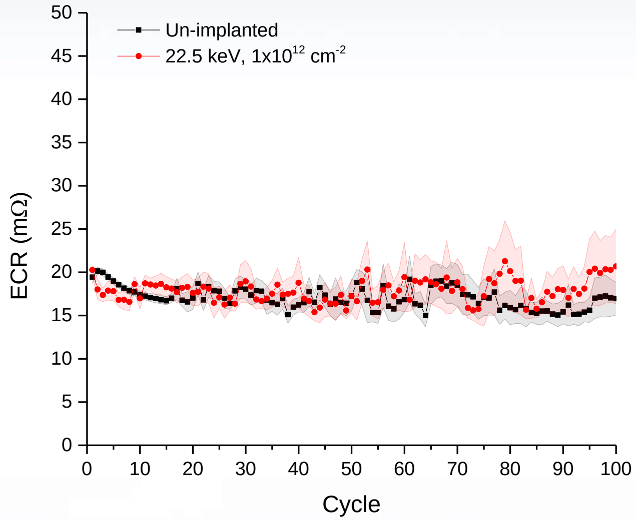
Electrical Contact Resistance and Wear Measurements

Collaborators: J-E Mogonye & S.V. Prasad

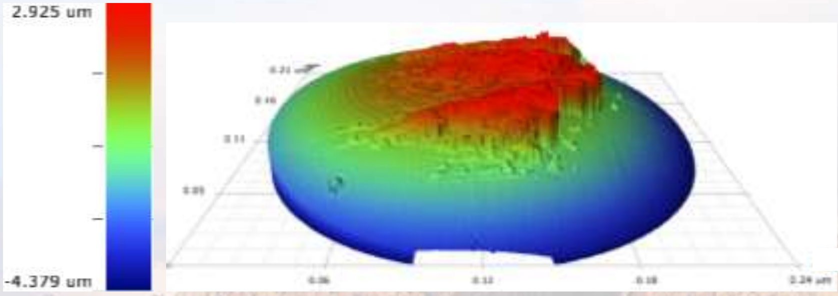




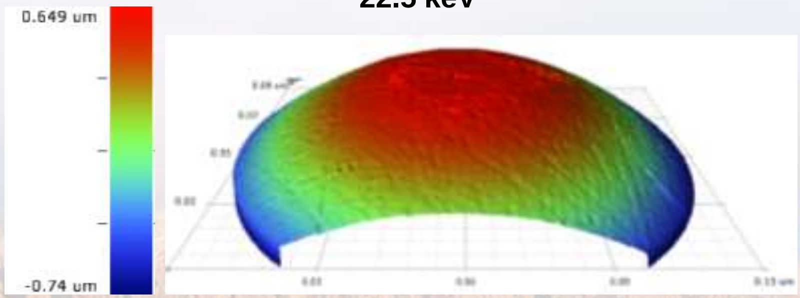
Friction is significantly reduced with ^{3}He implantation while maintaining ECR performance

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 in ECR

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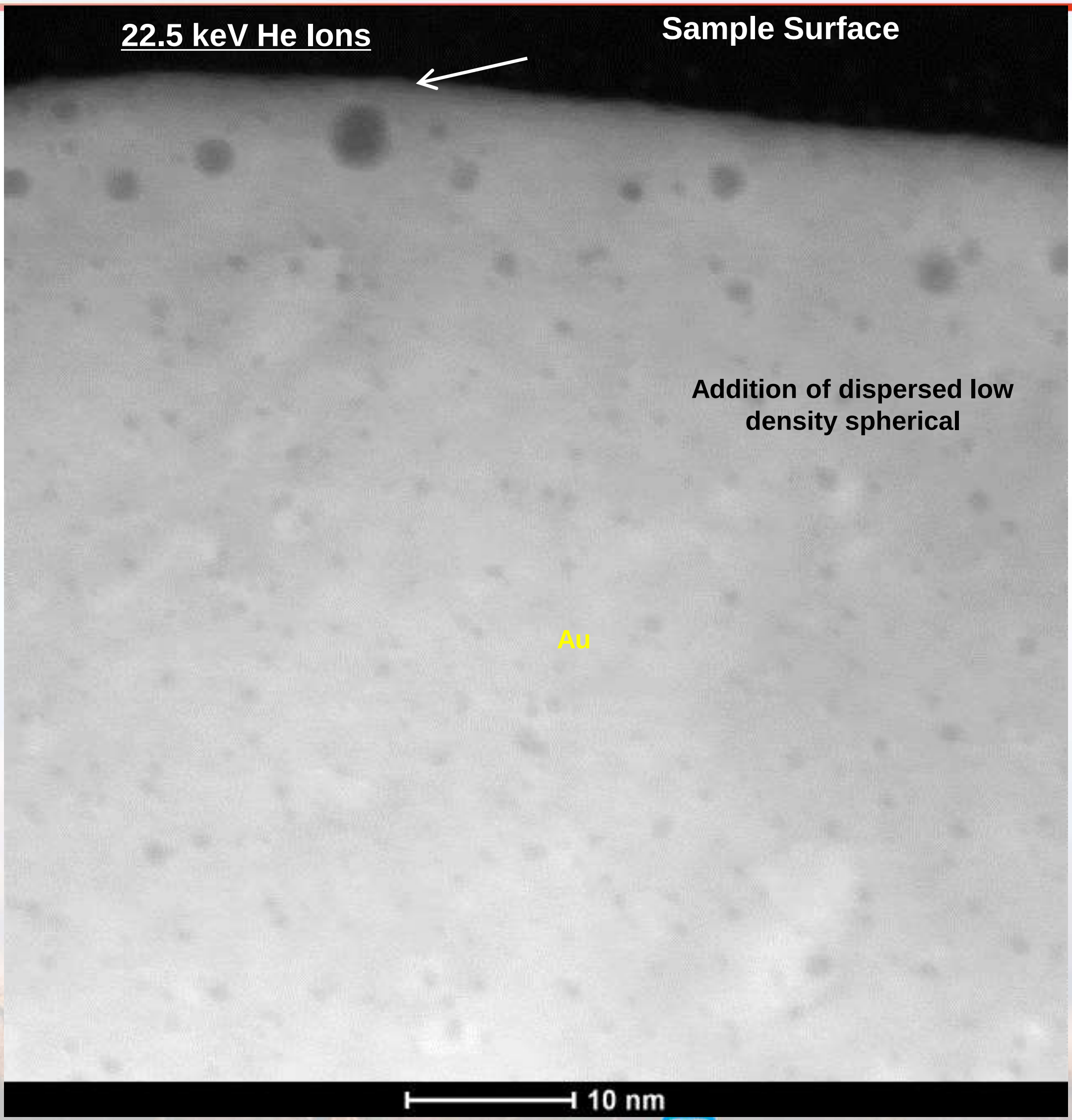
Modeling and STEM of He Implantation

Collaborators: J-E Mogonye & S.V. Prasad

- **Simulations: SRIM 2008**
- **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**

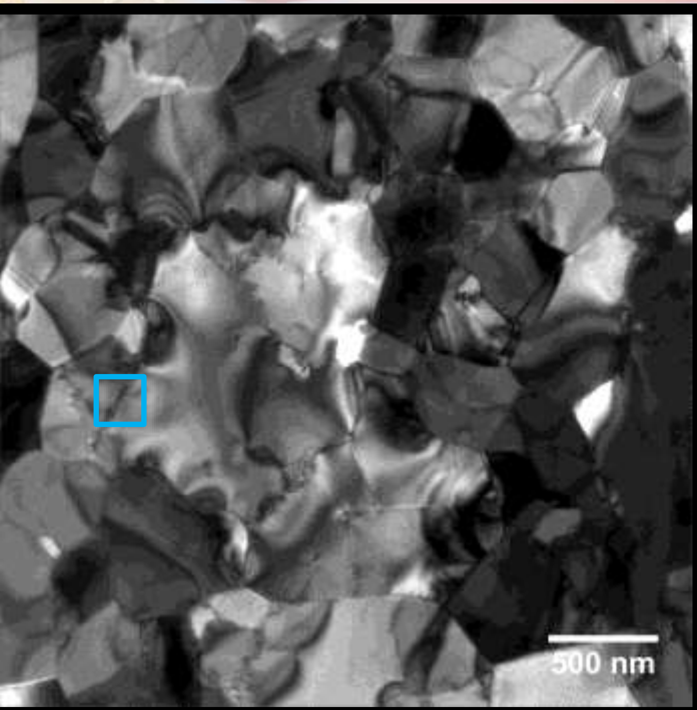
- **AC-STEM used to observe the distribution of implanted bubbles**
- **Bubble locations are in good agreement with SRIM ion range predictions**

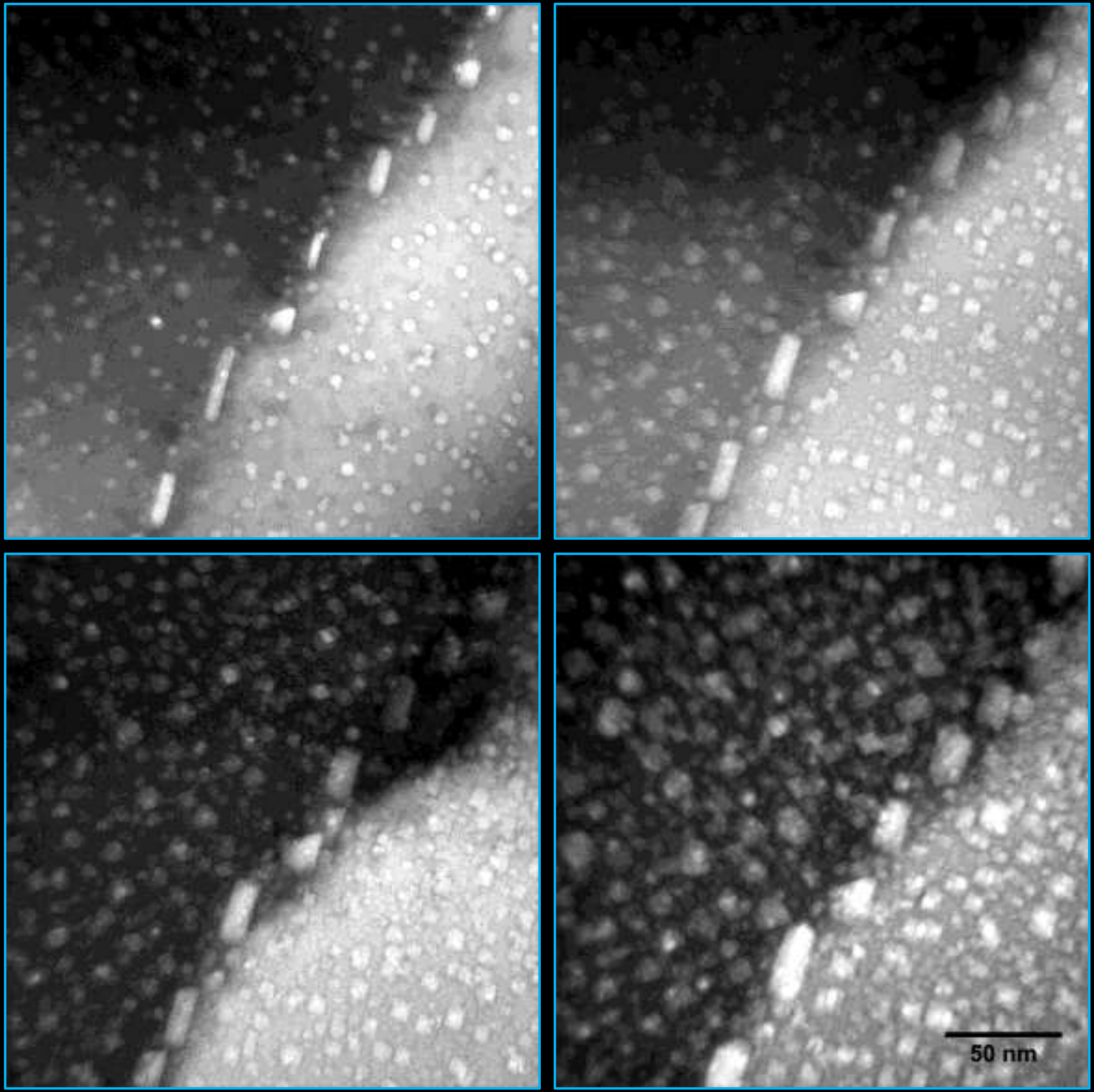


He implantation result in small dispersed spherical structures assumed to be He bubbles. Dispersion and depth can be tailored

In situ Implantation

Collaborators: C. Chisholm & A. Minor





Gold thin-film implanted with 10keV He^{2+}

Result: porous microstructure

Cumulative Effects of Ion Irradiation as a Function of Ion Energy and Au Particle Size

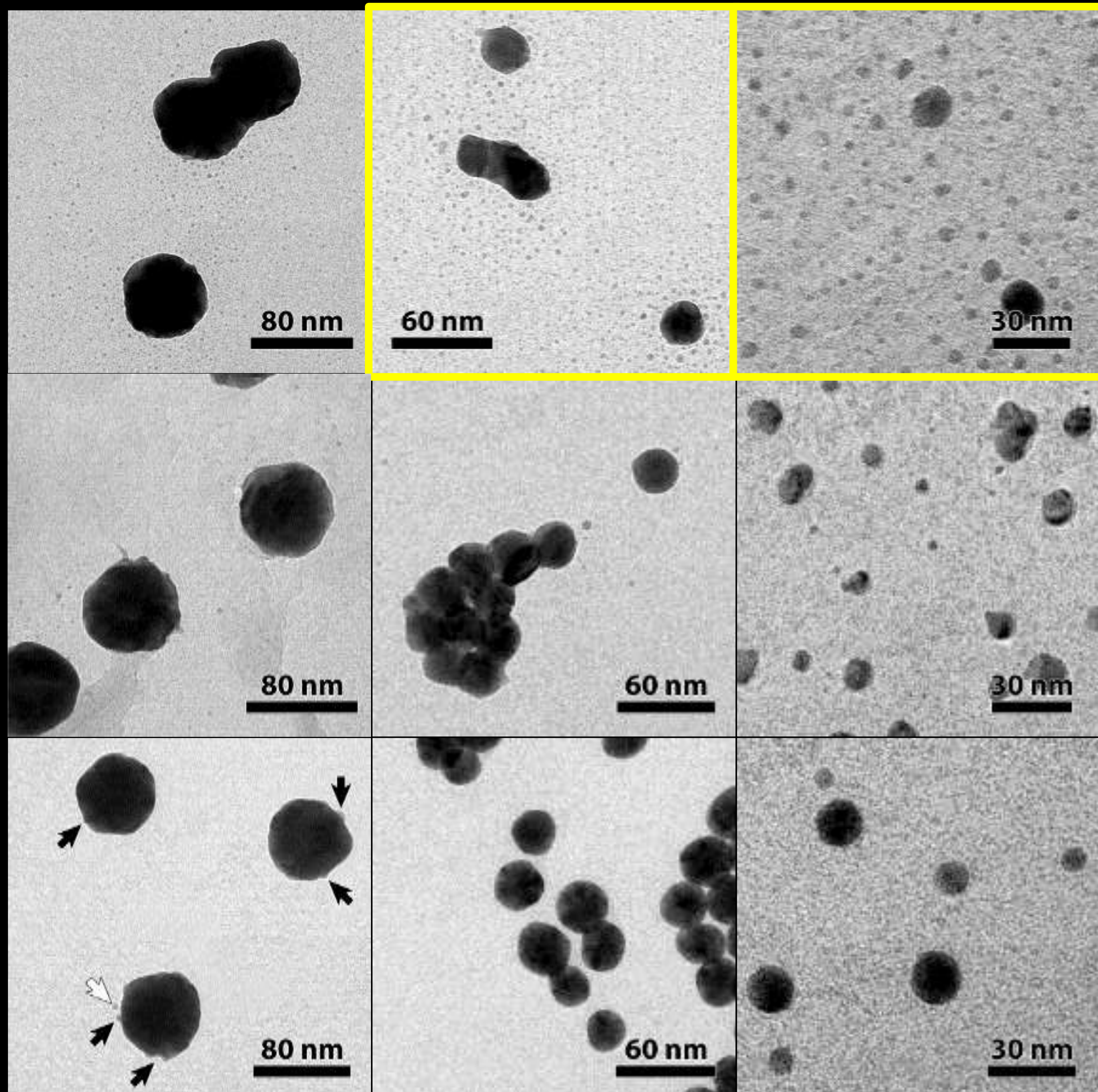
Collaborator: D.C. Bufford

60 nm | 20 nm | 5 nm

46 keV Au^{1-}
3.4×10^{14} $/cm^2$

2.8 MeV Au^{4+}
4×10^{13} $/cm^2$

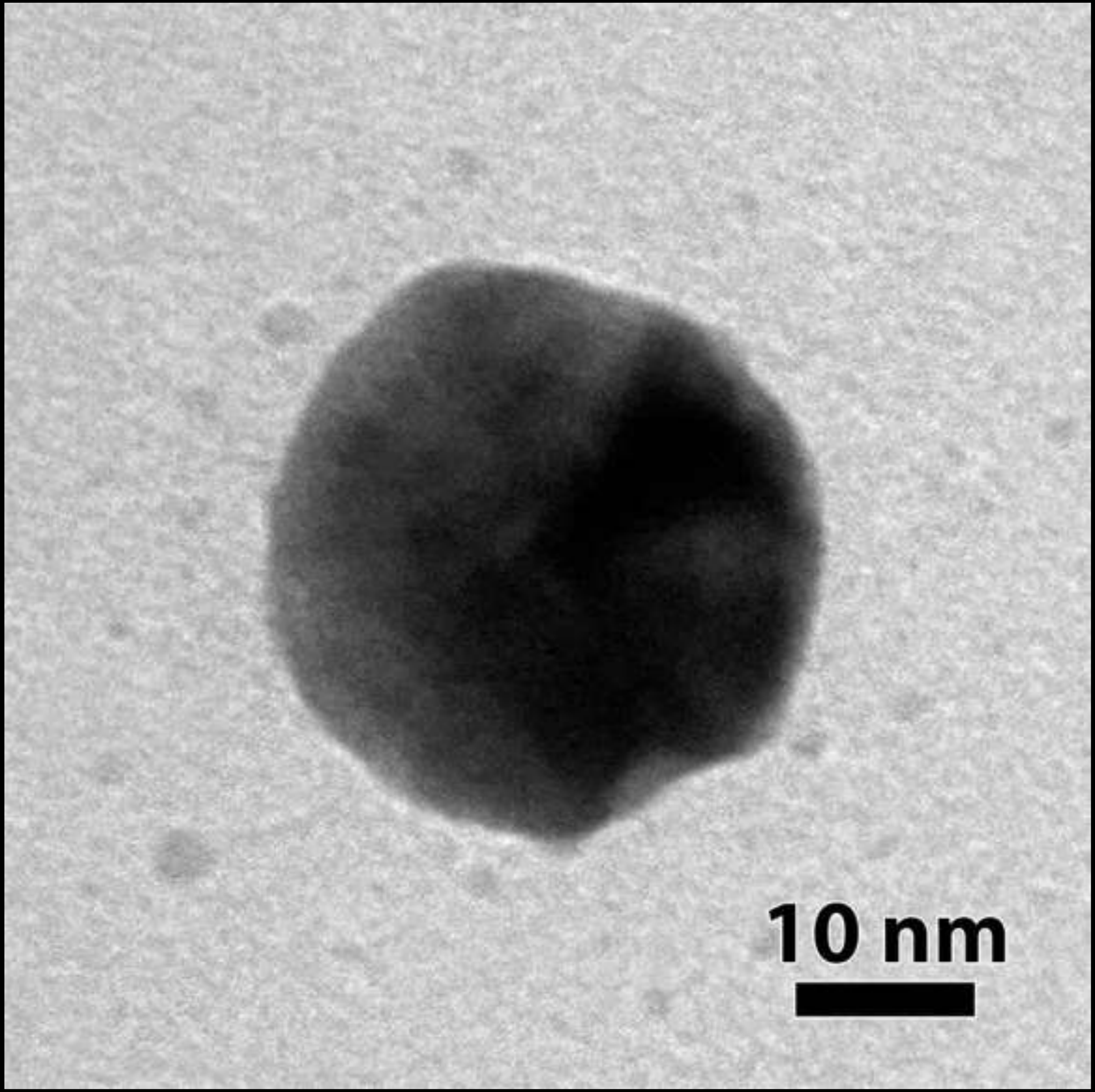
10 MeV Au^{8+}
1.3×10^{12} $/cm^2$

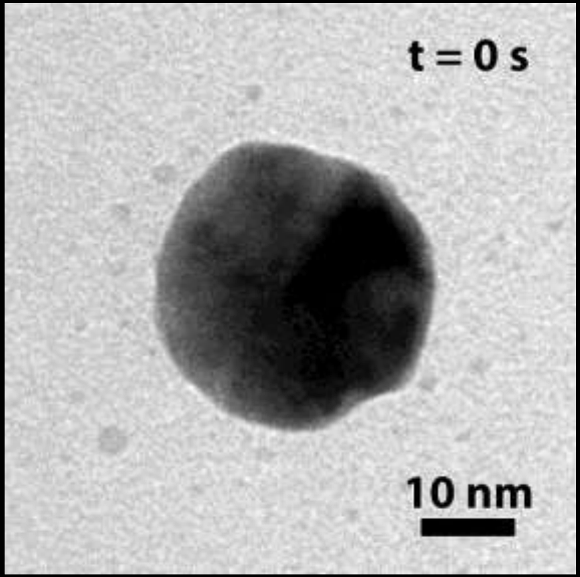


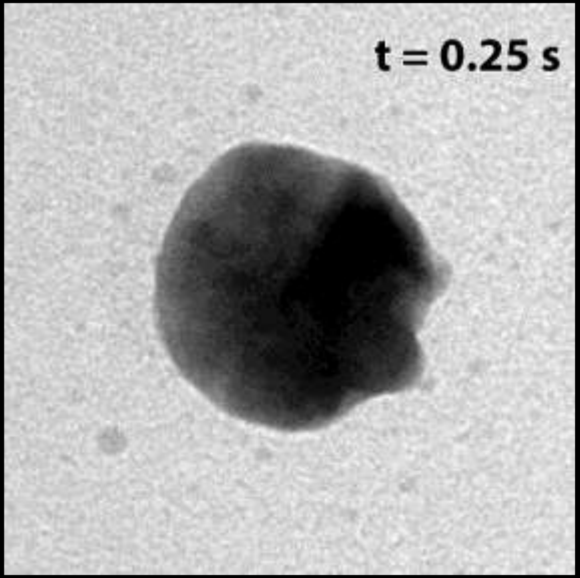
Particle and ion energy dictate the ratio of sputtering, particle motion, particle agglomeration, and other active mechanisms

Single Ion Effects with 46 keV Au^{1-} ions: 20 nm

Collaborator: D.C. Bufford

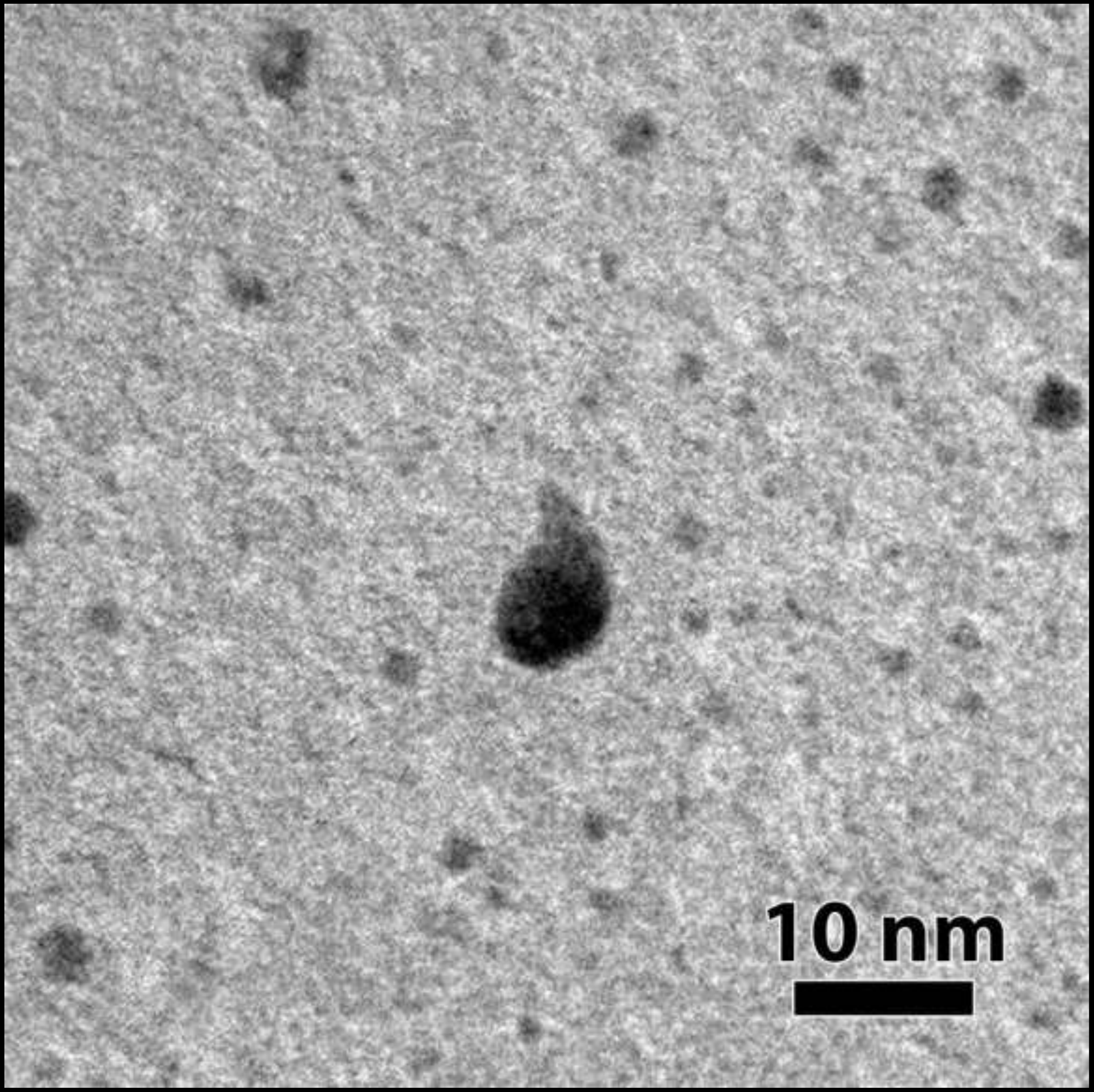


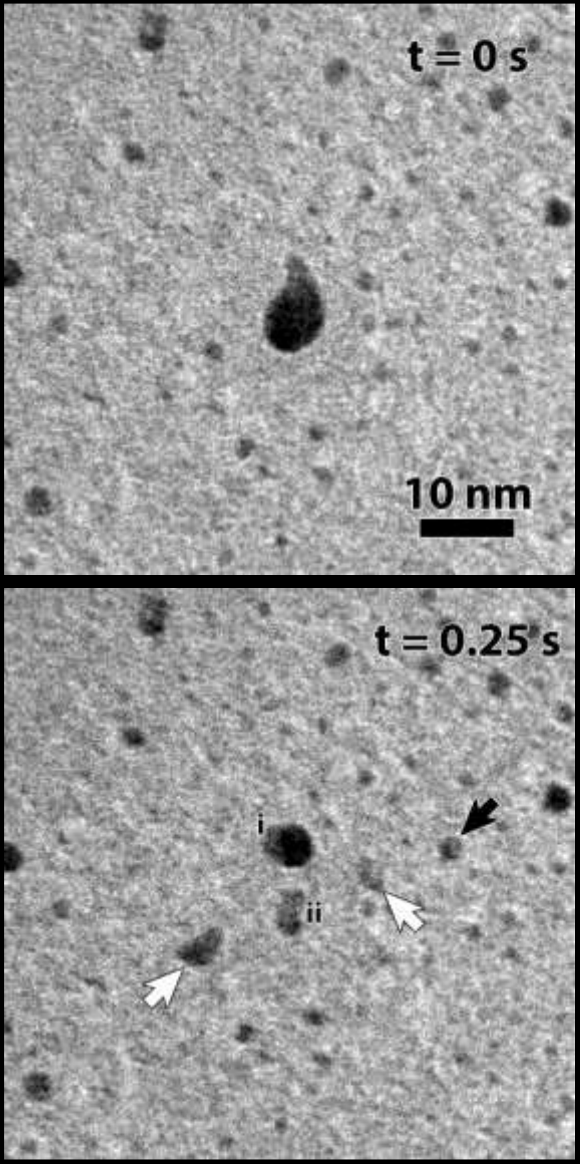




Single Ion Effects with 46 keV Au^{1-} ions: 5 nm

Collaborator: D.C. Bufford



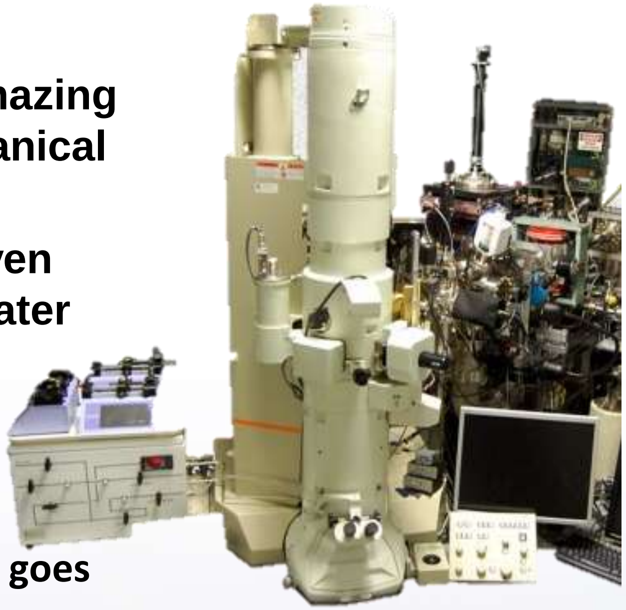


Summary

- **Ion Beam Modification (IBM) has been shown to be an amazing tool in tailoring the thermal, optical, electrical, and mechanical properties of many material systems**
- **New capabilities and juxtaposing of techniques permit even greater insight into the governing physics permitting greater control of properties and performance.**
- **Sandia's I^{3}TEM is one of a few in the world**

  ***In situ* irradiation from H to Au** ***In situ* gas implantation**

  combinations of in-situ techniques
- **We are still a long way away from a complete design process that goes from fundamental physics to system engineering**



Collaborators:

- **IBL: D.C. Bufford, D. Buller, C. Chisholm, B.G. Clark, B.L. Doyle, S. H. Pratt, & M.T. Marshall**
- **Sandia: B. Boyce, T.J. Boyle, P.J. Cappillino, J.A. Scott, B.W. Jacobs, M.A. Hekmaty, D.B. Robinson, E. Carnes, J. Brinker, D. Sasaki, J.A. Sharon, T. Nenoff, W.M. Mook**
- **External: A. Minor, L.R. Parent, I. Arslan, H. Bei, E.P. George, P. Hosemann, D. Gross, J. Kacher, & I.M. Robertson**

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