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The *In situ* Ion Irradiation TEM (I^3TEM)

Khalid Hattar

Center for Integrated Nanotechnologies Leveraged Facility, (505) 845-9859, khattar@sandia.gov

U.S. DEPARTMENT OF ENERGY
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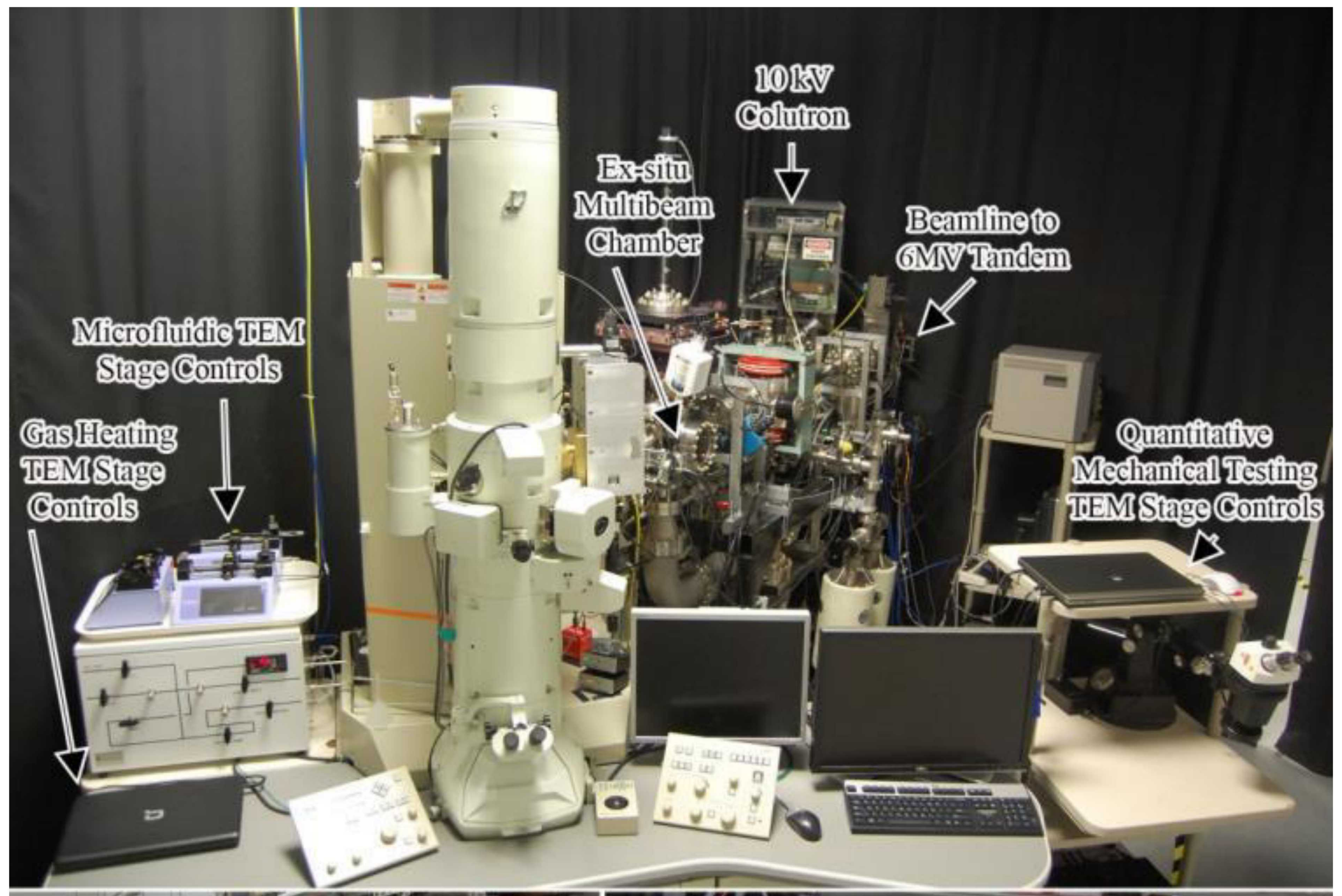
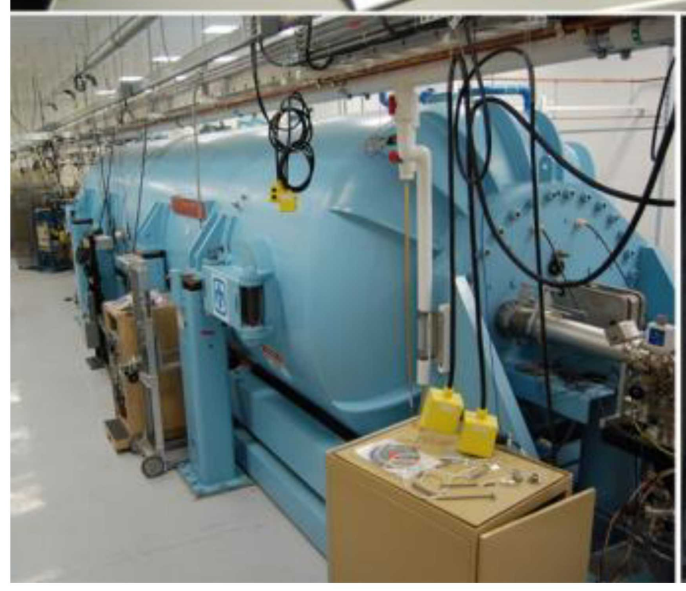
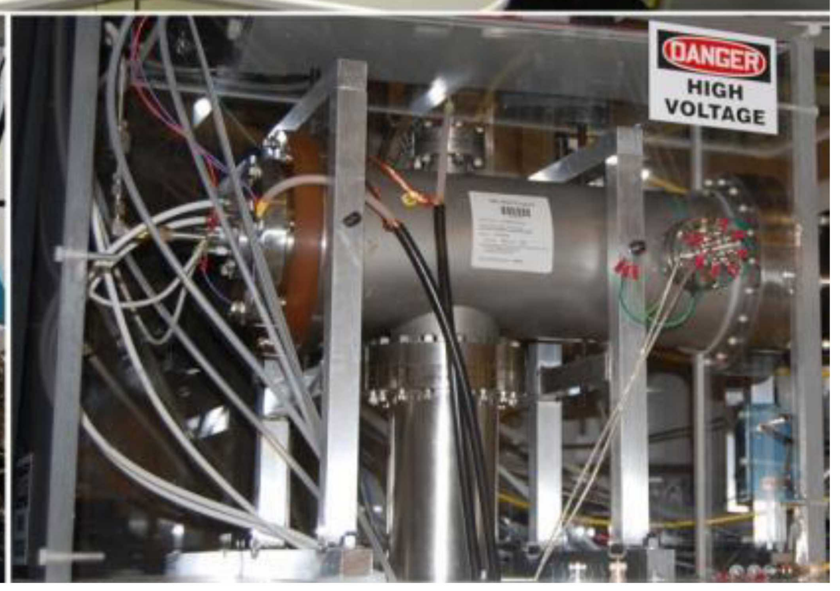
I^3TEM Capabilities

I^3TEM Facility



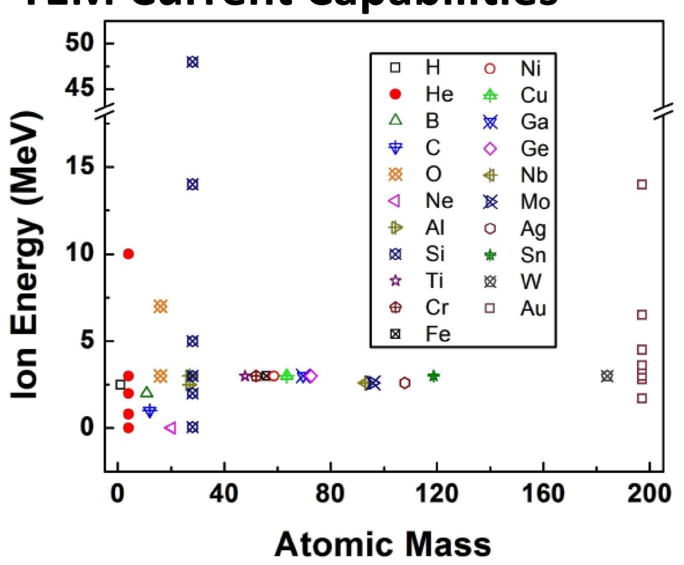




The I^3TEM combines a 200 kV TEM, a 6 MV Tandem Accelerator, and a 10 kV Colutron with a range of advanced TEM stages. Permitting both sequential, concurrent, and limited triple beam ion irradiation.

K. Hattar, D.C. Bufford, D.L. Buller, Daniel NIM:B (2014), pp. 56-65

I^3TEM Current Capabilities



- High energy ion irradiation (H to Au)
- Implantation of gasses and metals
- Electron tomography (±81˚)
- Limited triple beam experiments (Heavy ion with 10 keV He and D_2)
- Sample temperature 77K to 1,273K
- Gas flow and heated environments
- Two-port liquid mixing environments
- Qualitative mechanical testing
- Precession Electron Diffraction (PED)

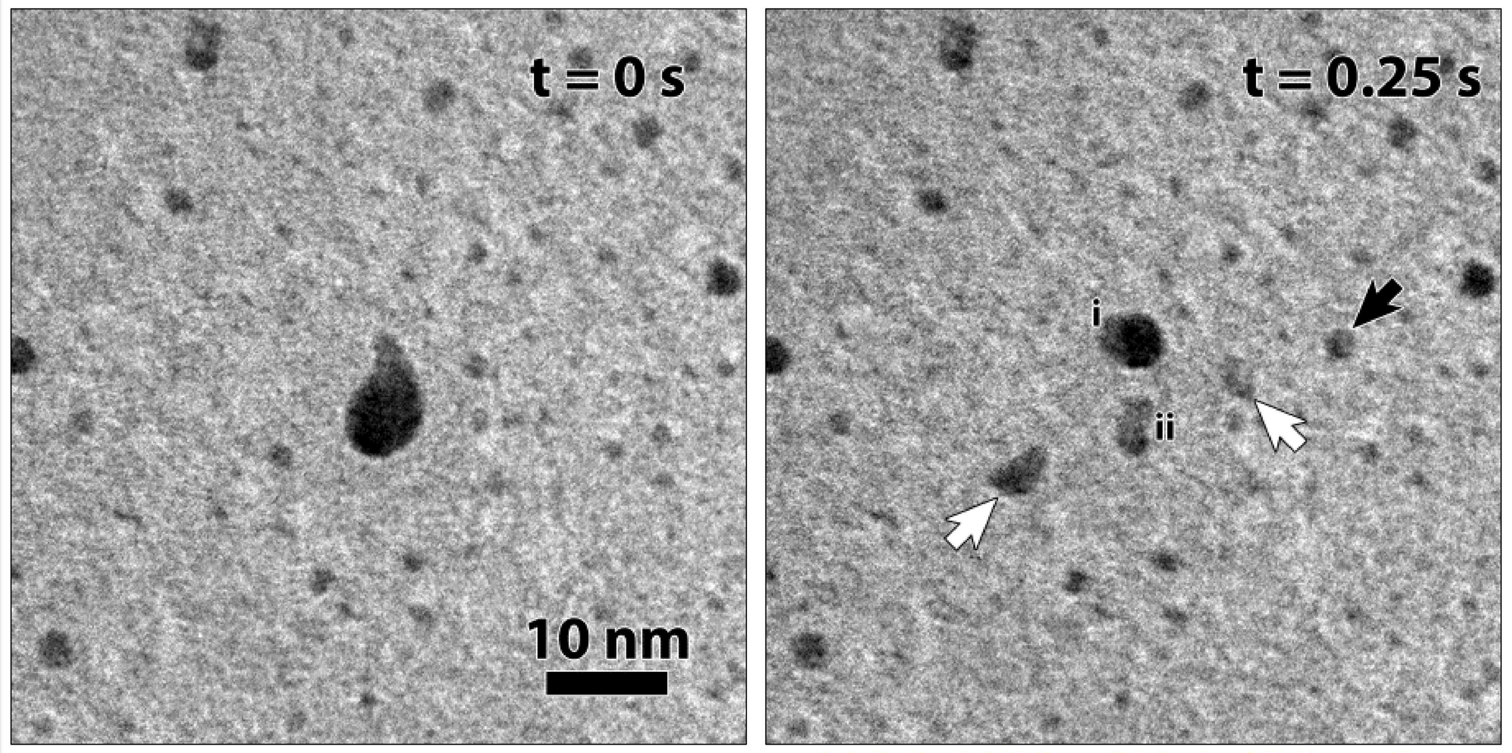
A plot of ion species and energies introduced into the TEM. Recently 370 eV He was introduced

Planned Additional Capabilities

- *In situ* Cathodoluminescence (CL) and Ion Beam Induced Luminescence (IBIL)
- DTEM permitting nanosecond resolution
- Addition of a 1 MV NEC Tandem to complete the energy range
- Bending magnet upgrade to permit up to 100 MeV Au

Nanoscale Observation of Radiation Events

Single Ion Strike of 46 keV Au^{1-} into 5 nm Au nanoparticles

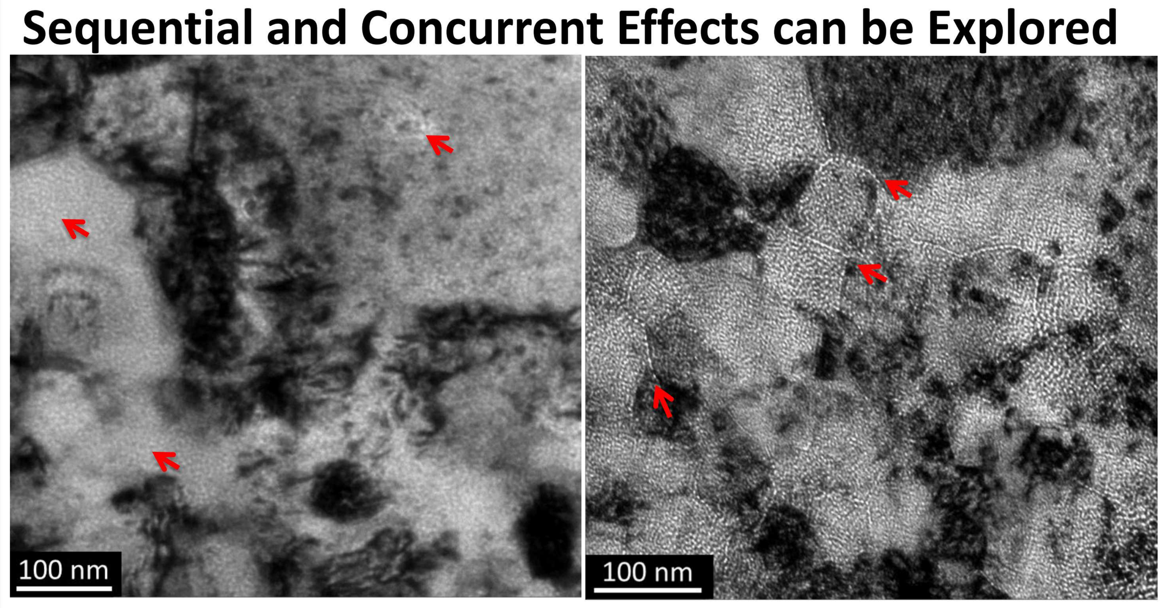


The fundamentals of radiation effects and ion beam modification can be studied in any TEM sample under a range of environments.

D.C. Bufford, S.H. Pratt, T.J. Boyle, & K. Hattar. Chem. Commun. 50, no. 57 (2014), pp.7593-7596.

D.C. Bufford & K. Hattar. JMR 29:20 (2014): 2387-2397.

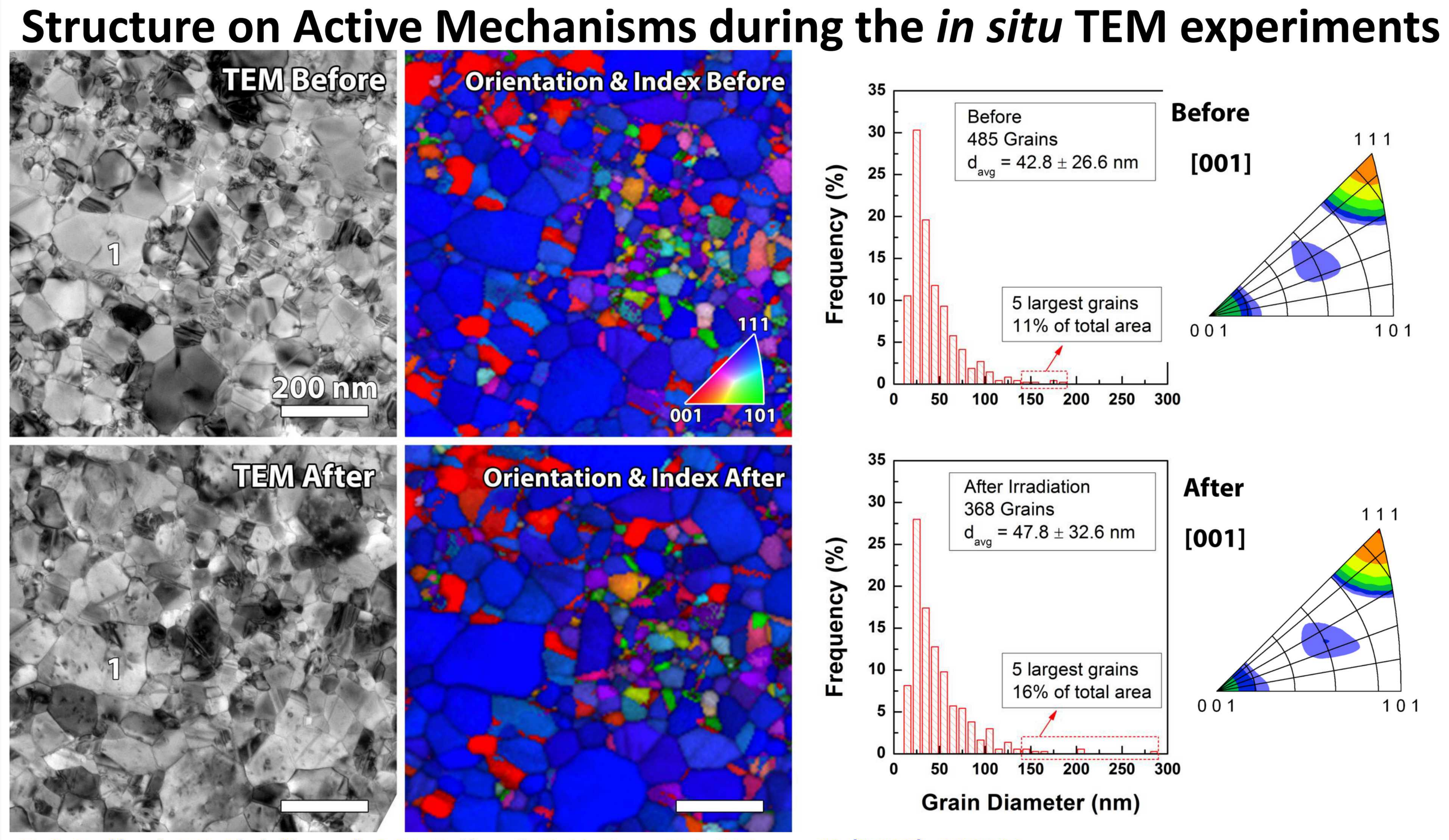
Sequential and Concurrent Effects can be Explored



Multiple accelerators permit tailoring of radiation conditions. The order of 10 keV He and 3 MeV self-ion irradiation in Ni dictates where He bubbles form.

B.R. Muntifering, *et al.* MRL (2015): 1-8.

Orientation Mapping Provides Rapid Insight into the Role of Local Structure on Active Mechanisms during the *in situ* TEM experiments



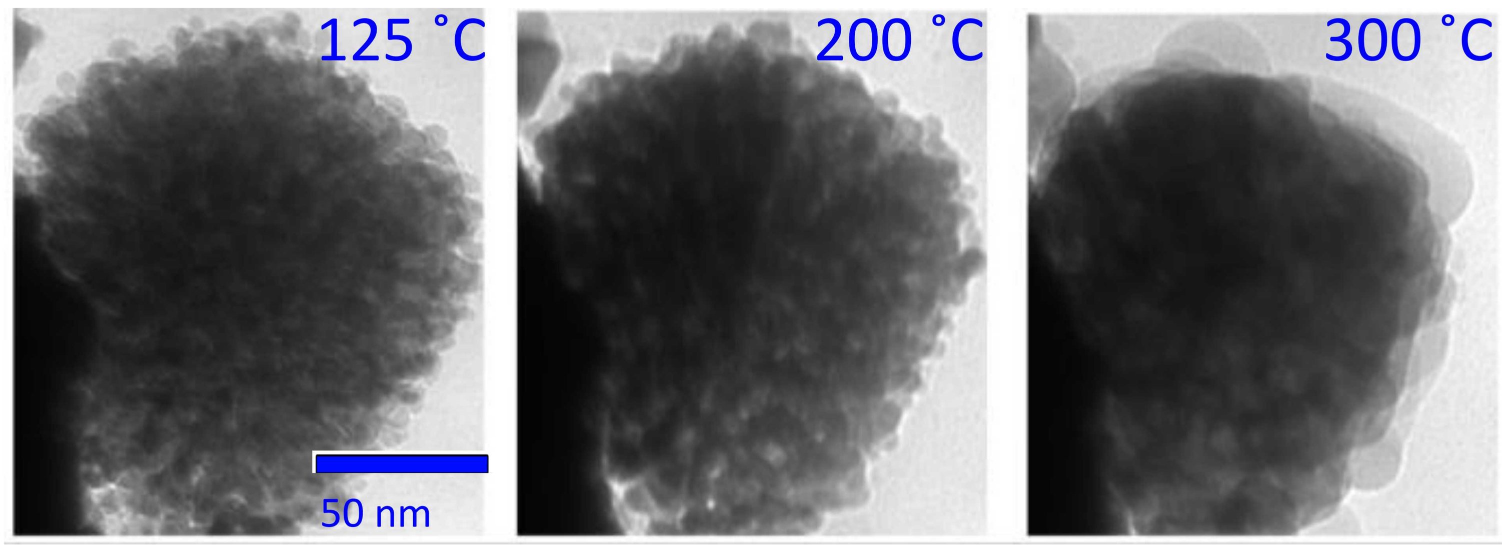
D.C. Bufford, F.F. Abdeljawad, S.M. Foiles, & K. Hattar. APL 107, no. 19 (2015): 191901.

Associated Team Members and Collaborators

- D.L. Buller, J.A. Scott, M.T. Marshall, R. Sisson, D.C. Bufford, and B.R. Muntifering
- Fadi F. Abdeljawad, Mark D. Allendorf, Corbette Battaile, Thomas E. Beechem III, Brad L. Boyce, Timothy J. Boyle, Darren W. Branch, Thomas Buchheit, Daniel C. Bufford, Daniel, L. Buller, Jay D. Carroll, Michael Chandross, Blythe G. Clark, Remi P.M. Dingreville, F. Patrick Doty, Barney L. Doyle, Matthew Eichenfield, Patrick L. Feng, Stephen M. Foiles, David M. Follstaedt (retired), Ronald Goeke, Steven H. Goods (retied), Aaron C. Hall, Michelle A. Hekmaty, Bernadette A. Hernandez-Sanchez, Sara J. Homeijer, Jon F. Ihlefeld, James A. Knapp (retied), Paul G. Kotula, Jonathan Madison, Douglas L. Medlin, Joesph Michael, William M. Mook, Tina M. Nenoff, Roy H. Olsson III, Henry A. Padilla II, Edward S. Piekos, S. V. Prasad, Sarah H. Pratt, Joseph D. Puskar, David B. Robinson, Mark A. Rodriguez, Pylin Sarobol, Darryl Y. Sasaki, Peter A. Sharma, Vitalie Stavila, Vina Tikare, Gyorgy Vizkelethy, Michael Wiwi, Pin Yang, and Jonathan A. Zimmerman
- ANL: Mark Kirk, Meimei Li, Pete Baldo (retired); LANL: Osman Anderoglu, J. Kevin Baldwin, Patricia Dickerson, Nan Li, Stuart A. Maloy, Cheng Sun, Blas P. Uberuaga, Yong Wang; ORNL: Philip D. Edmondson; Drexel: Osman El-Atwani, Christopher Barr, James E. Nathaniel, Mitra L. Taheri, Christopher Weinberger, Garrett Tucker; Georgia Tech: Kacher, Josh, Arron Dunn; Northwestern: Brittany R. Muntifering; RPI: Robert Hull; Stony Brook U.: Olivia Donaldson, Jason Trelewicz; Texas A&M: Michael Demkowicz; Tufts Univ: Jianmin Qu; U. of Alabama: Gregory B. Thompson, Luke N. Brewer; UCB: Chisholm, Claire, Andrew M. Minor, Peter Hosemann; UCSB: Daniel S. Gianola; UIUC: J.P. Allain; UM: Amit Misra; UNT: Jon-Erik Mogonye, Thomas W. Scharf; UT-Austin: Paulo J. Ferreira; UVa: Ramez Cheaito, Caroline S. Gorham, Patrick E. Hopkins; U. Wisc.: Ian M. Robertson; Oxford: Xiaoou Yi, Michael L. Jenkins, Steve G. Roberts; Univ. of Huddersfield: Jonathan A. Hinks, Steve E. Donnelly; Exxon-Mobile: Jamey A. Fenske IBM: Frances M. Ross; Intel: Shreyas, Rajasekhara, K.J. Ganesh, Janelle Villone; Nanomegas: Amith Darba; Protochips: Benjamin W. Jacobs; TerraPower: Gregory A. Vetterick;

Additional Extreme Environments

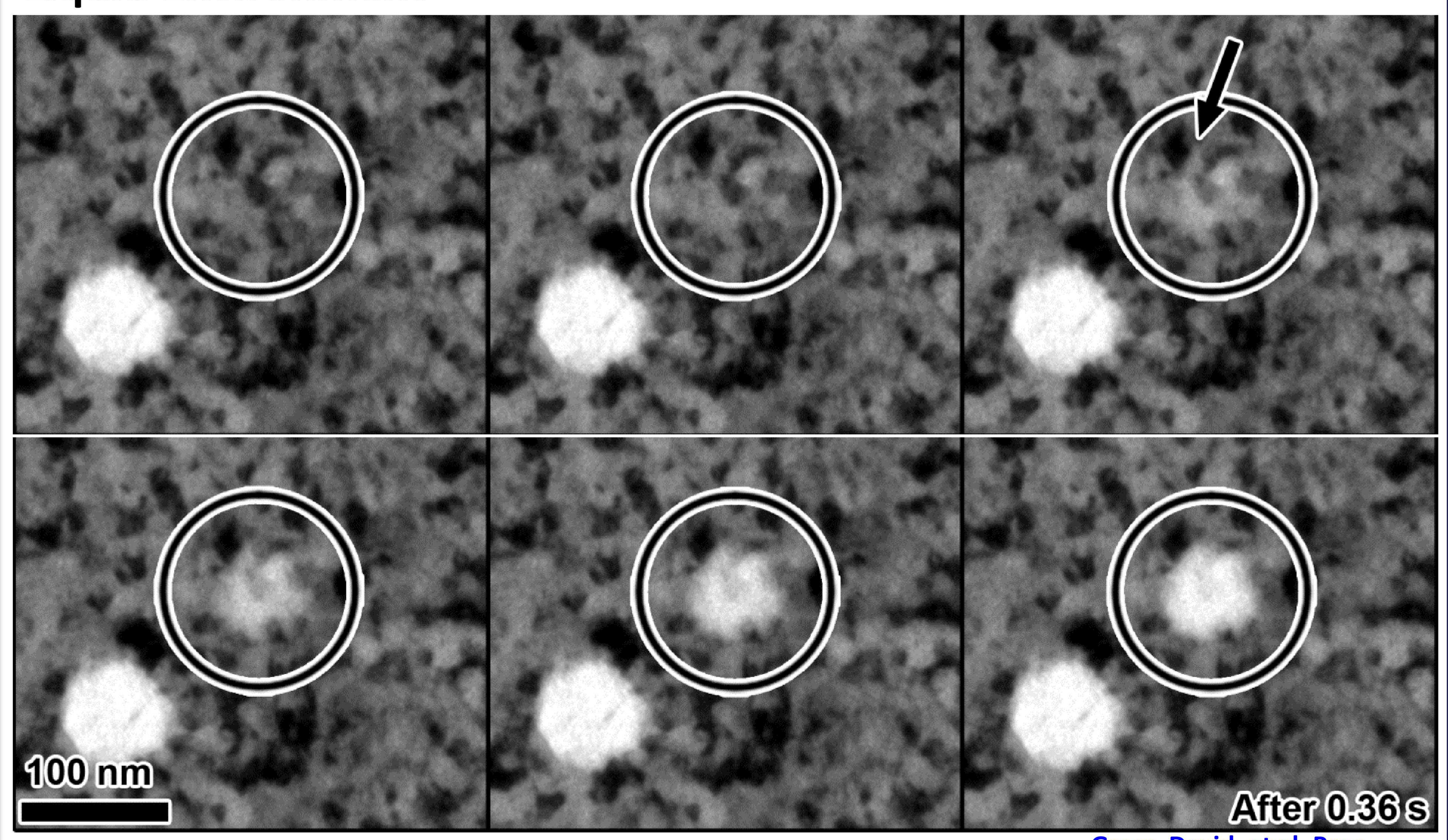
Gas Environment



The response of nonporous Pd nanoparticles were explored as a function of temperature and H_2 gas pressure. Pore collapsed significantly lower temperature than when annealed in vacuum.

P.J. Cappillino J. Mat. Chem. A 1, no. 3 (2013): 602-610.

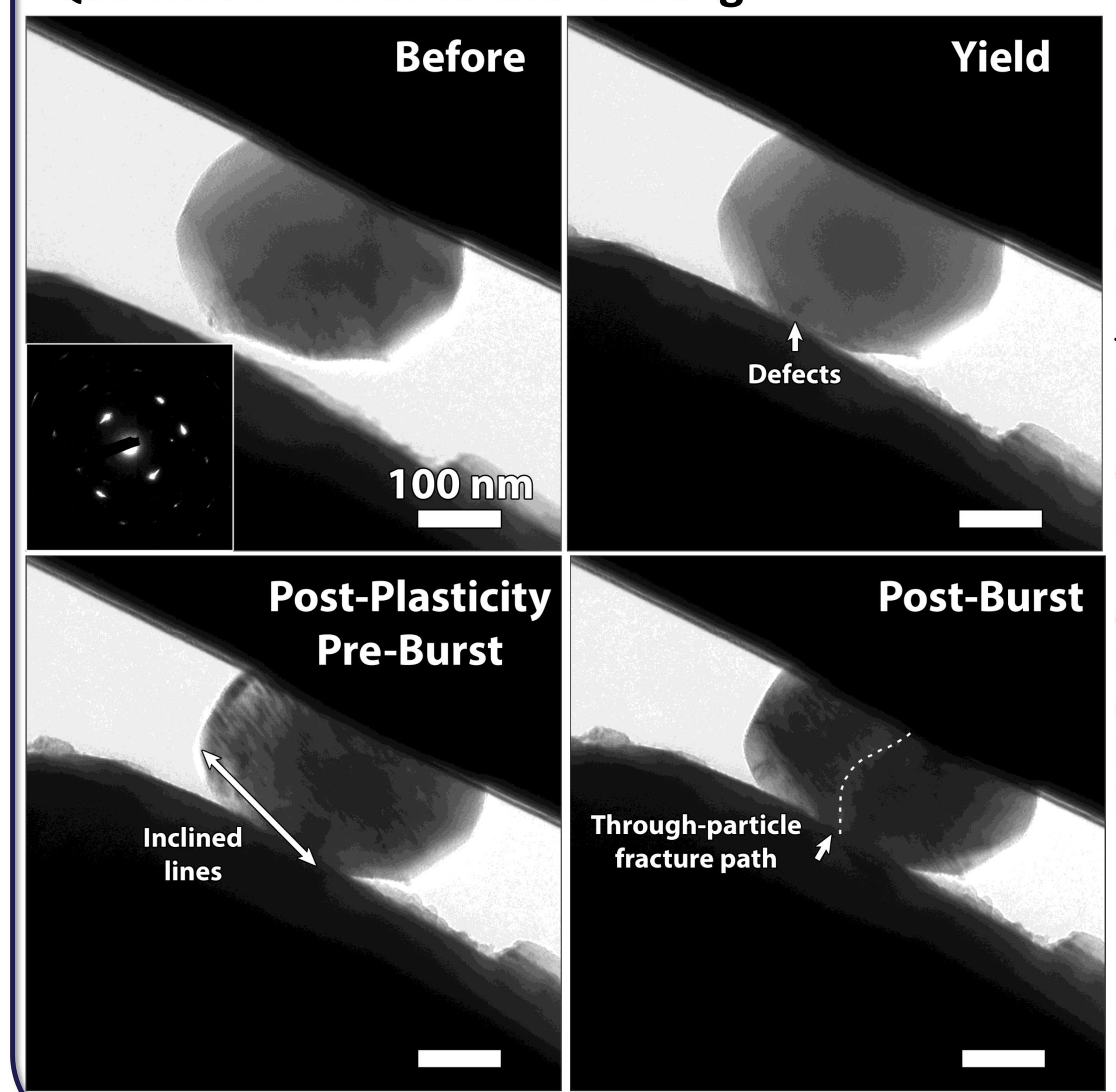
Liquid Environment



Nanoscale insight into liquid-solid interactions can be probed through *in situ* microfluidic TEM experiments. Here, pitting initiation is investigated in nanocrystalline Fe exposed to acetic acid.

Gross, David, et al. Proc. Prop. & Design of Adv. Cer. & Comp. II 261 (2017): 329. S.W. Chee, et al. Chem. Commun. 51, no. 1 (2014): 168-171.

Quantitative Mechanical Testing



Quantitative mechanical measurement during *in situ* TEM observation permits direct correlation between the structural evolution and the mechanical properties. Here, the deformation and failure of Al_2O_3 nanoparticles can be directly observed and local mechanisms can be identified.

P. Sarobol, *et al.* J. Thermal Spray Technology 25, no. 1-2 (2016): 82-93.

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