NANOTECHNOLOGIES

UTAustin Portugal

# In-Situ Aberration-Corrected TEM Nanoindentation of Silver Nanoparticles

*C.E.Carlton[1,2], T.Aoki[3], Y.Zhu[4], M.J.Caturla[5], F.Zorro[6,7], P.J.Ferreira[1,6,7]*

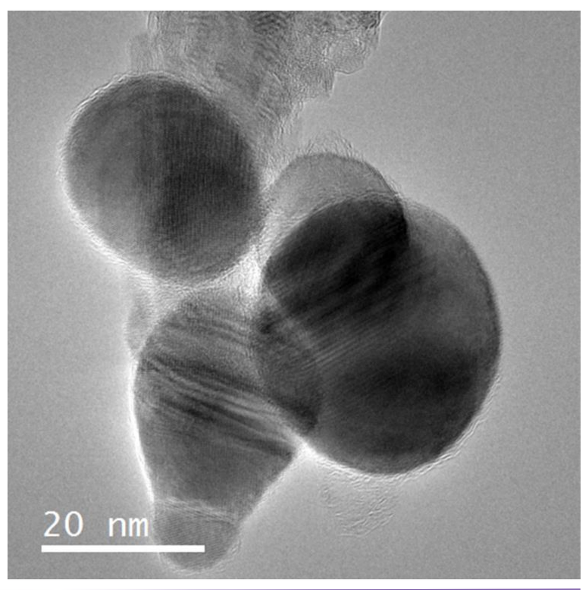
1. Materials Science and Engineering Program, University of Texas at Austin;
2. Samsung Semiconductor;
3. LeRoy Eyring Center for Solid State Science, Arizona State University;
4. Department of Condensed Matter Physics and Materials Science, Brookhaven National Laboratory;
5. Applied Physics Department, Alicante University;
6. Advanced Electron Microscopy Imaging and Spectroscopy Department, International Iberian Nanotechnology Laboratory, Braga, Portugal;
7. Mechanical Engineering Department and IDMEC, Instituto Superior Técnico, University of Lisbon.

## Background

Single-crystalline nanoparticles play an increasing important role in a wide variety of fields including advanced materials, catalysts for fuel cells, energetic materials. However their deformation mechanisms are still poorly understood, in particular the role played by single dislocations. As a result in this study we propose to understand the deformation mechanisms in nanoparticles and consequently nucleate and analyze the behavior of dislocations.

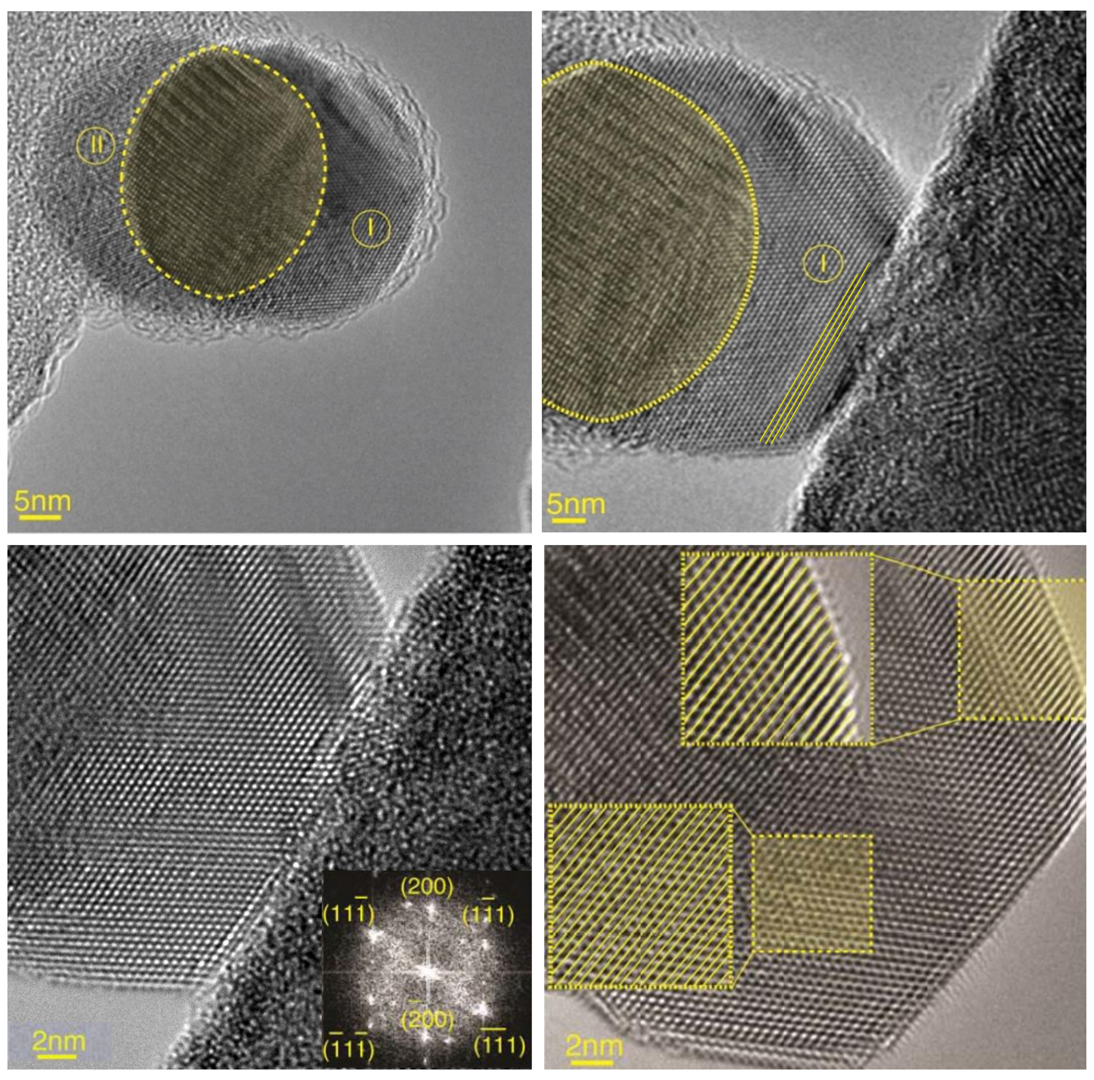
## Methodology

Silver nanoparticles with an average size 20nm were deposited onto a gold wire support, which was affixed to the stationary holder of the Nanofactory Instruments stage. The tungsten probe was carefully affixed to the moving end of the specimen holder, which was then inserted into the TEM column. To conduct the in-situ nanoindentation experiments, the probe and the sample were brought close to one another. Subsequently, the Ag nanoparticles were compressed in-situ and imaged using phase-contrast at 200 keV in a double aberration-corrected JEOL 2200 TEM located at Brookhaven National Laboratory.




## Results

Sequence of aberration-corrected TEM images showing the in-situ nanoindentation process.




- There are no dislocations in the nanoparticle in its pristine state.
- It is oriented with the surface normal parallel to the $[0\bar{1}\bar{1}]$ direction.
- A terminating extra-half plane is clear along the $(0\bar{1}1)$ planes.
- One of the $(\bar{1}\bar{1}1)$ planes is missing and a shear is also visible.

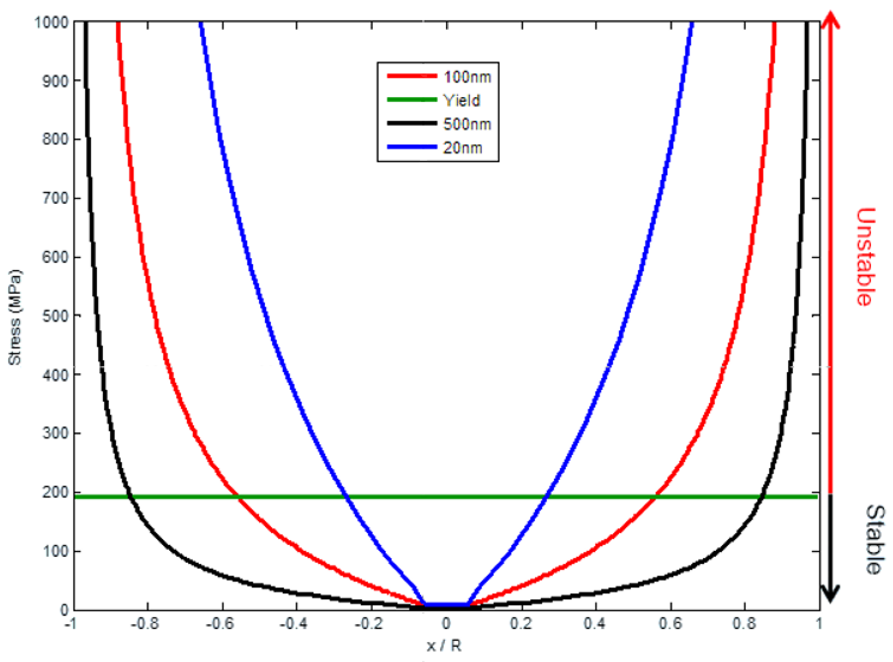
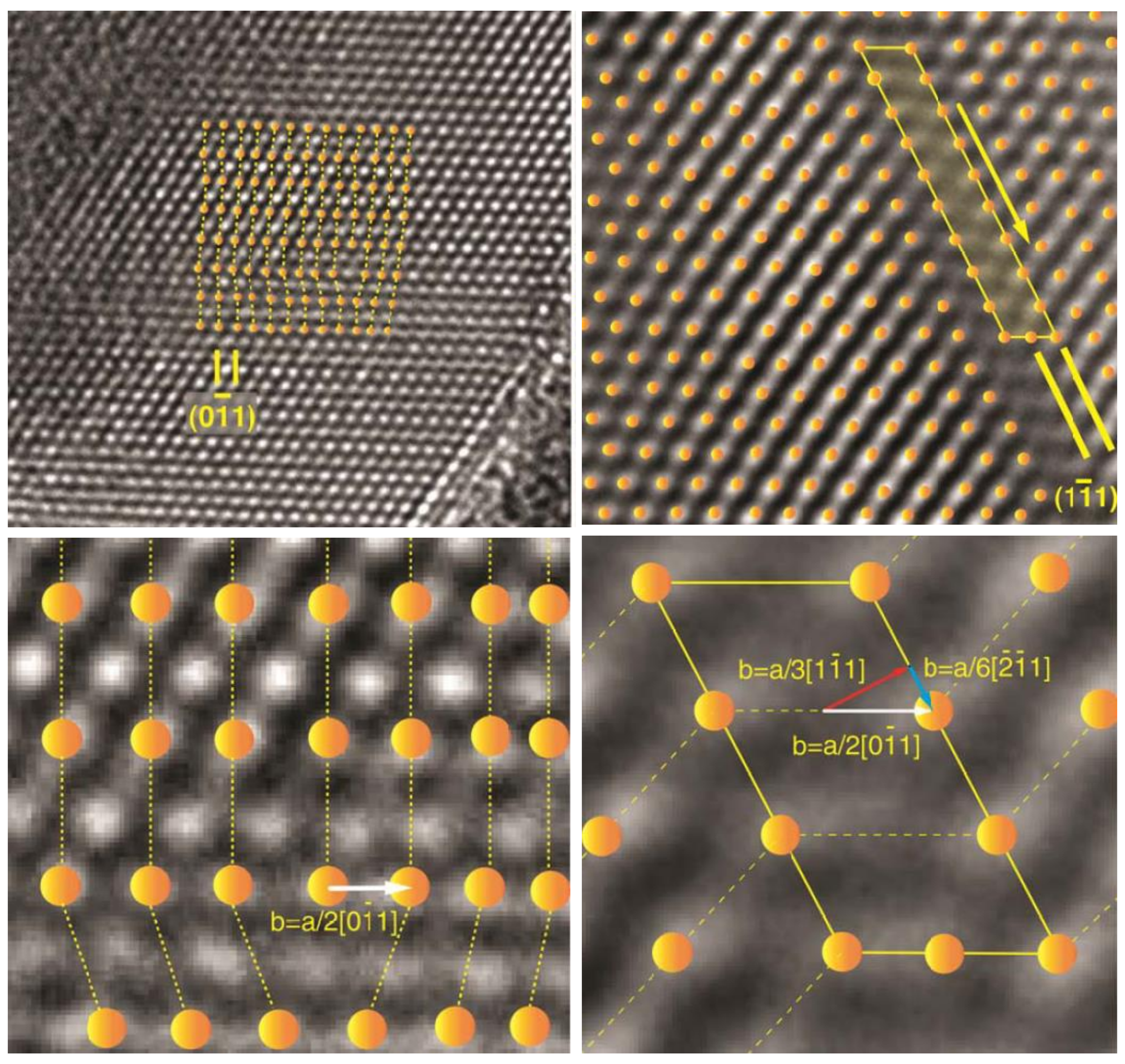



Image stresses vs nanoparticles diameter

Dislocation Propagation:
Climb: Frank dislocation loop
Glide: Shockley partial

Sequence of aberration-corrected TEM images showing the defects present during the indentation




Frank dislocation loop: Missing Plane
Shockley partial dislocation: Shear Displacement
Perfect Dislocation

## Conclusions

This research shows that the nucleation of single perfect and partial dislocations, as well as dislocation glide occurs in metallic fcc nanoparticles with a size smaller than 20 nm. These dislocations are unstable due to the presence of image stresses associated with the nearby surfaces, and thus confirm the lack of dislocations typically observed in nanoparticles, even after significant deformation. In the case of nanoparticles, dislocations are likely to be much closer to the surface, thereby allowing also dislocation climb to occur even at room temperature. Consequently, nanoparticles seem to be self-healing, thereby ejecting dislocations towards the free surface.

UTAustin Portugal · FCT Fundação para a Ciência e a Tecnologia · TEXAS The University of Texas at Austin · Universidad de Alicante · BROOKHAVEN NATIONAL LABORATORY · TÉCNICO LISBOA · Arizona State University 1885 · INL International Iberian Nanotechnology Laboratory