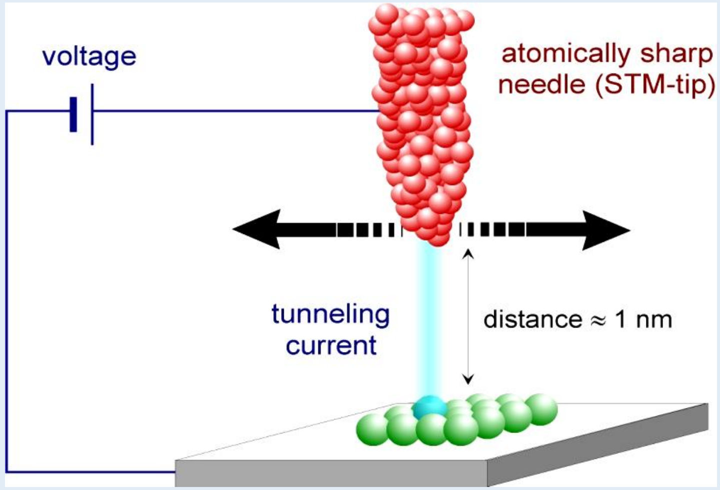
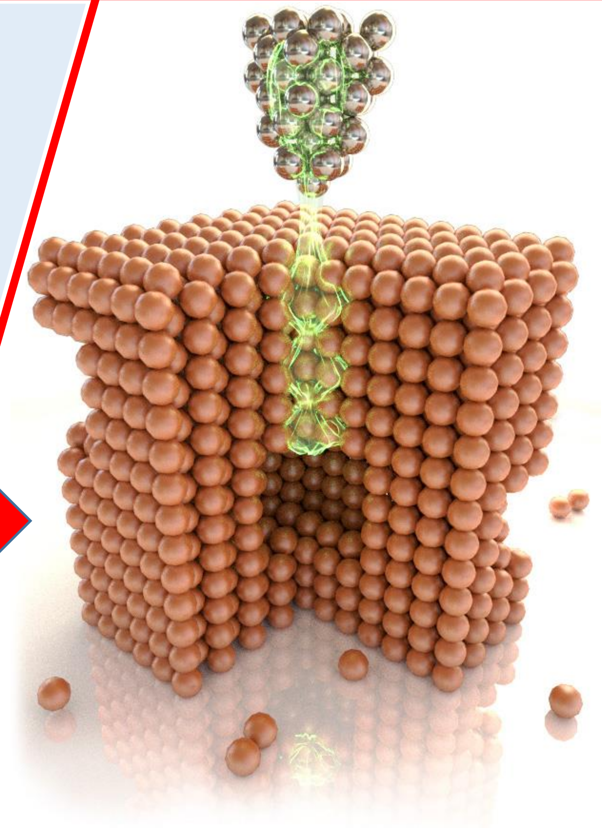
Can STM see below a surface?! Yes!!! Is it really possible? Sure, down to 100 nm !

Exploring a subsurface in metals with STM

O. Kurnosikov





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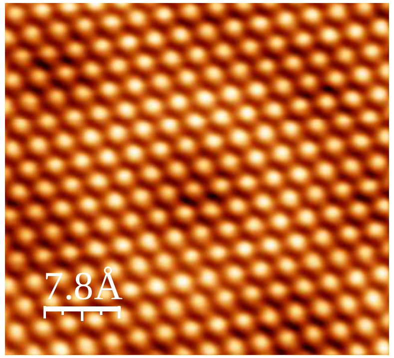
Where innovation starts

Introduction: Scanning Tunneling Microscopy/Spectroscopy

Topography

Cu(111)

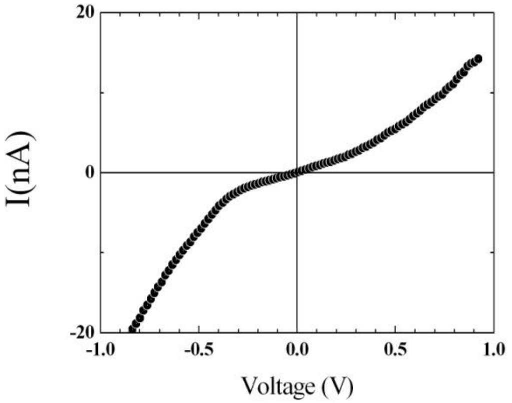


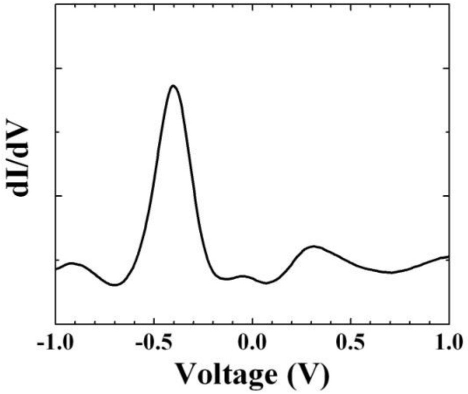
atomic resolution

Resolution
Lateral : atomic, ~0.1nm
Vertical : subatomic, ~0.001nm

Two ways of get the subsurface sensibility:
1. Subatomic variation of the relief
2. Perturbation of surface electron density

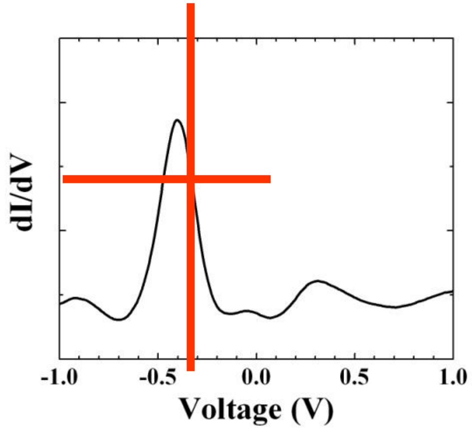
In selected points Spectroscopy (STS)

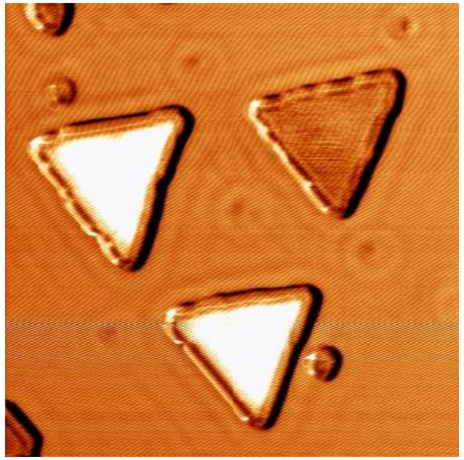




reflects the Density of States

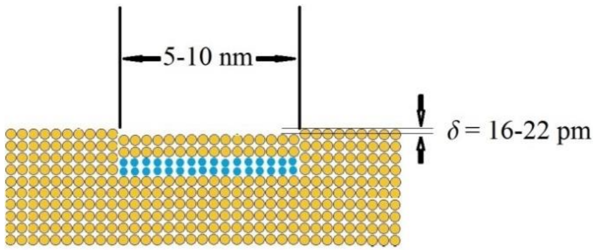
For each (x,y) Conductance mapping

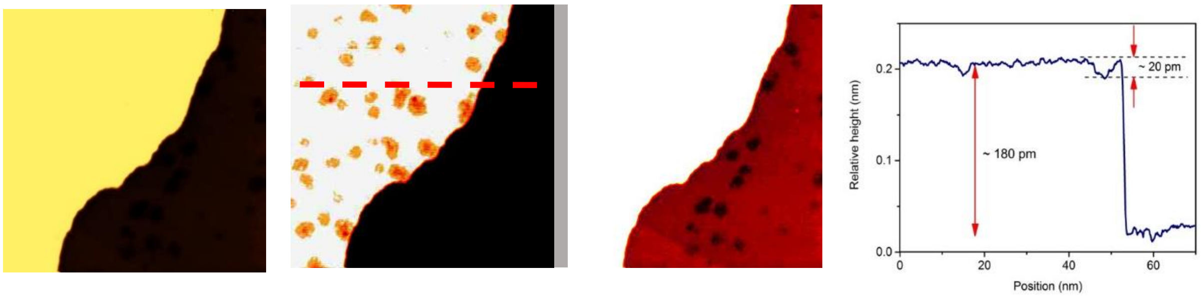




Relief variation

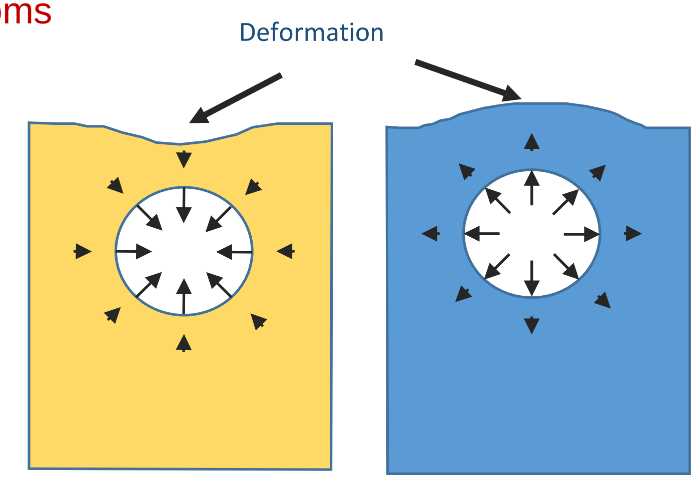
Mismatch of crystalline lattices of substrate and impurity atoms or embedded nanocluster .

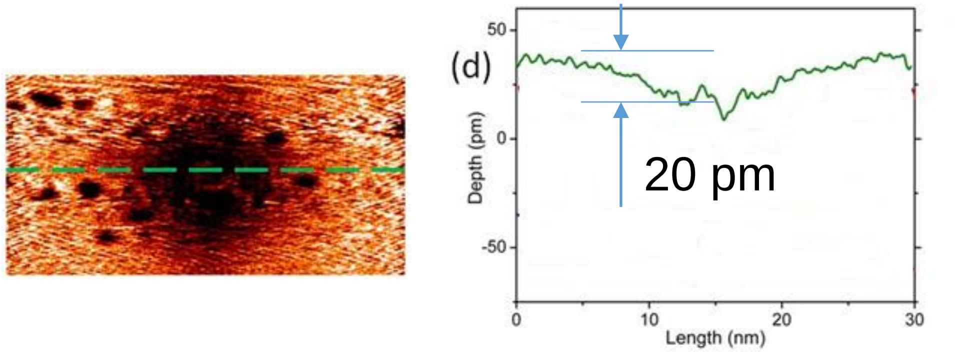




Co nanoclusters embedded below Cu(001) surface, 75 x 75 nm ^{2}.

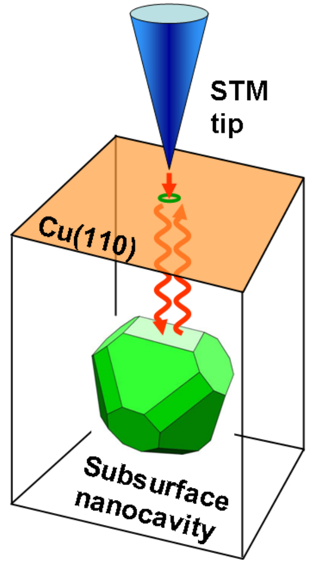
Relaxation of crystalline lattice and interaction of embedded atoms





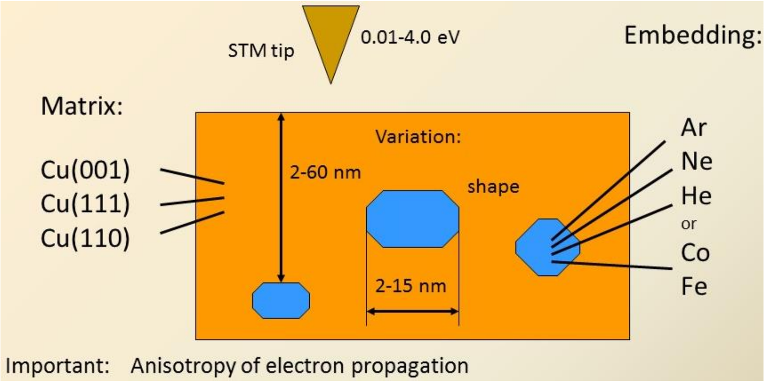
Ar bubble below Cu(001) surface, 30 x 15 nm ^{2}.

Buried nanocavities and clusters: TU/e results

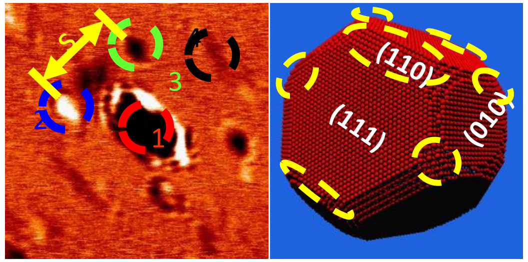


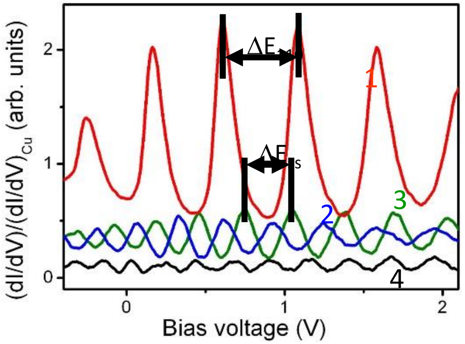
Ar-, Ne- or He- filled nanocavities have much stronger scattering effect and therefore they can be detected much dipper than single impurities atoms. The nanocavities are visualized in STM measurements as spots of different contrast above their locations. The contrast oscillates with bias. From the oscillation period the depth can be deduced. Different facets of nanocavities induce different oscillation phase and period. From this the shape and size of the nanocavity can be determined.

Studied system



Shape: different spots – different facets

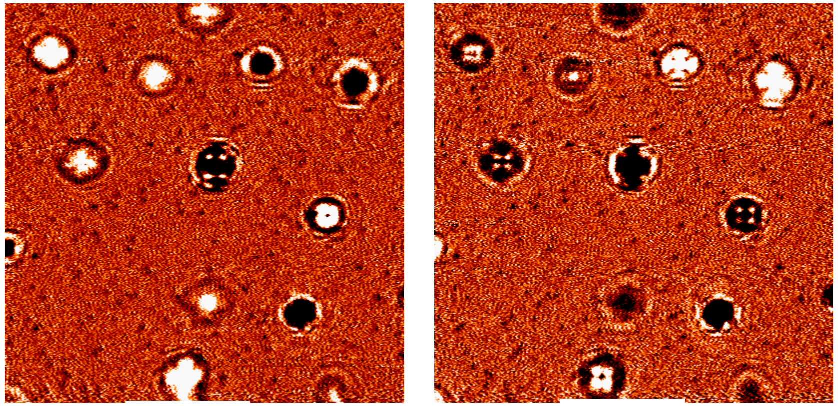




$$d = \frac{\pi}{\Delta E}\frac{\partial E}{\partial k}$$

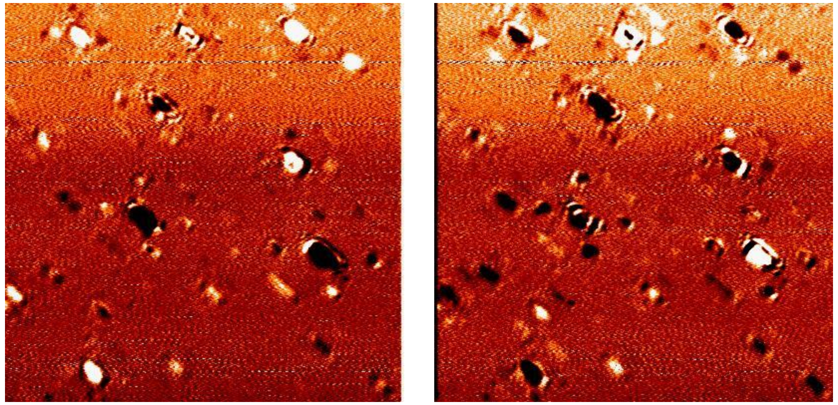
if ΔE=0,25 mV
then d = 12 nm

Ar nanocavities in Cu(001), the same area, different bias



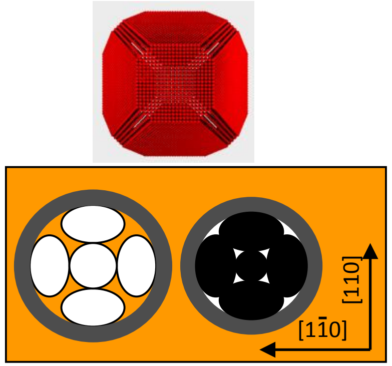
500mV 60×60 nm² 600mV

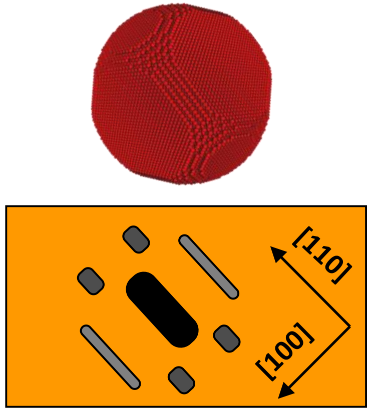
Ar nanocavities in Cu(110), the same area, different bias



400mV 60×60 nm² 500mV

What we have and what we see





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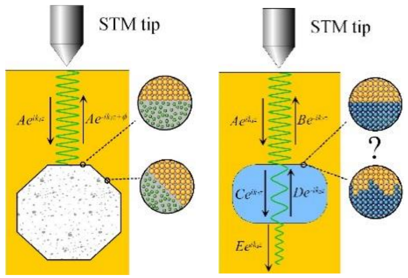
Ultimate depth detection: nanocavities in Cu(110) – 80 nm

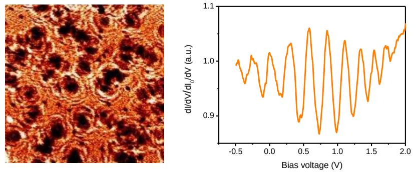
Nanocavities vs Nanoclusters



Metallic clusters provide less effective scattering. Nevertheless we can see Co and Fe nanoclusters up to 25 nm deep.

Co nanoclusters in Cu(001)

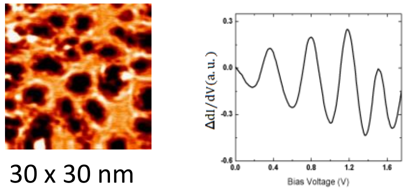
dI/dV @ 900mV   10 nm of Cu



40 x 40 nm

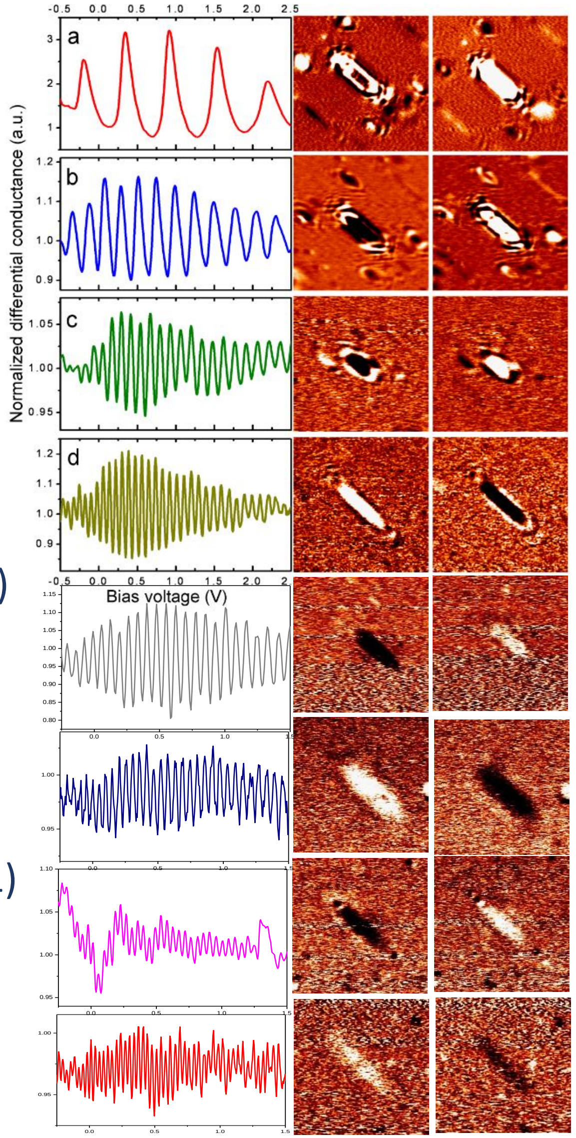
Fe nanoclusters in Cu(001)

dI/dV @ 400mV   6 nm of Cu



30 x 30 nm

Ar-filled nanocavities in Cu(110)



Depth

4.5 nm

12.5 nm

22.4 nm

32.5 nm

39.0 nm

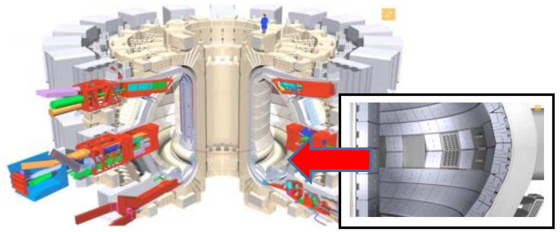
52.9 nm

62.8 nm

80.0 nm

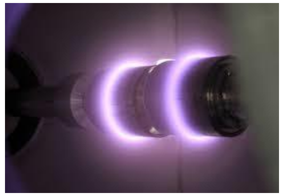
20 x 20 nm^2

Applications



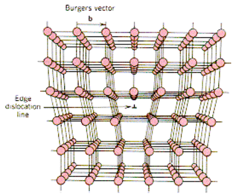
For ITER

Degradation of W or Mo walls by implantation and growth of H_2 and He-filled nanocavities: the growth of nanicavities can be visualizeed



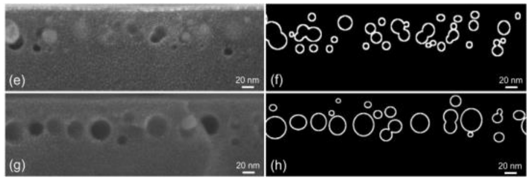
For micro- nanolithography

Ar, Ne, He implantation defects in conducting layers (Al, Cu, Au, Ag, …) during plasma processing or magnetron sputtering deposition



For clean material technology

Study near-surface defects and interfaces directly or by decoration them with He or H nanocavities



For solar cells and nanophotonics

Ge nanoclusters and nanovoids in fused silica

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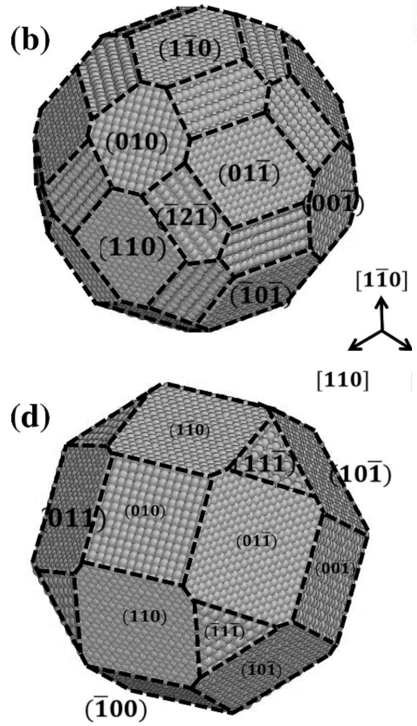
Application for ITER: Shape of nanocavity in W

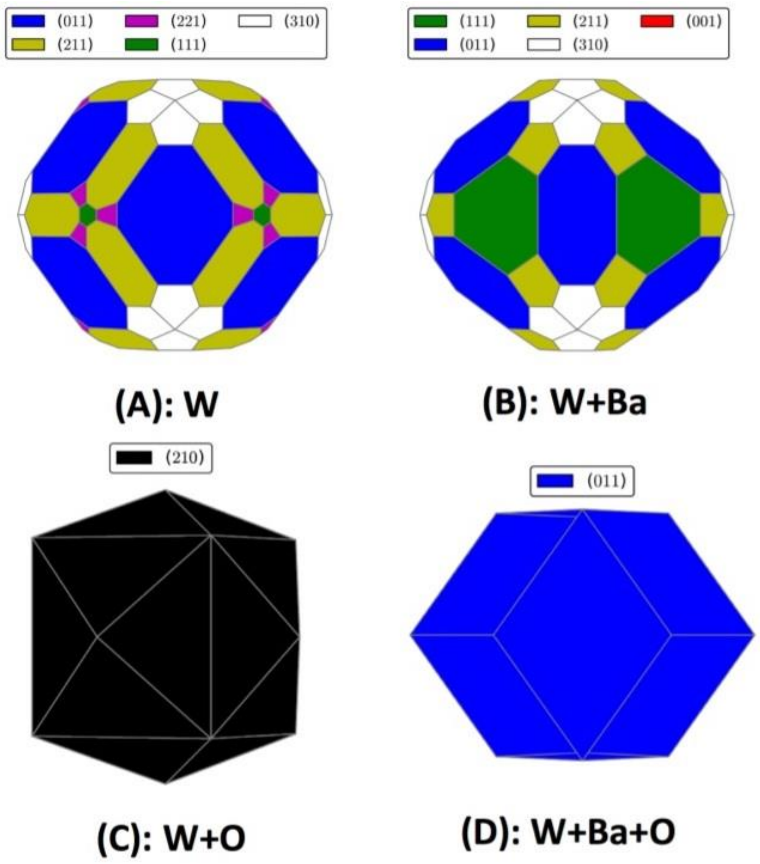
Possible Wulf constructions

Pure tungsten

Tungsten with impurities

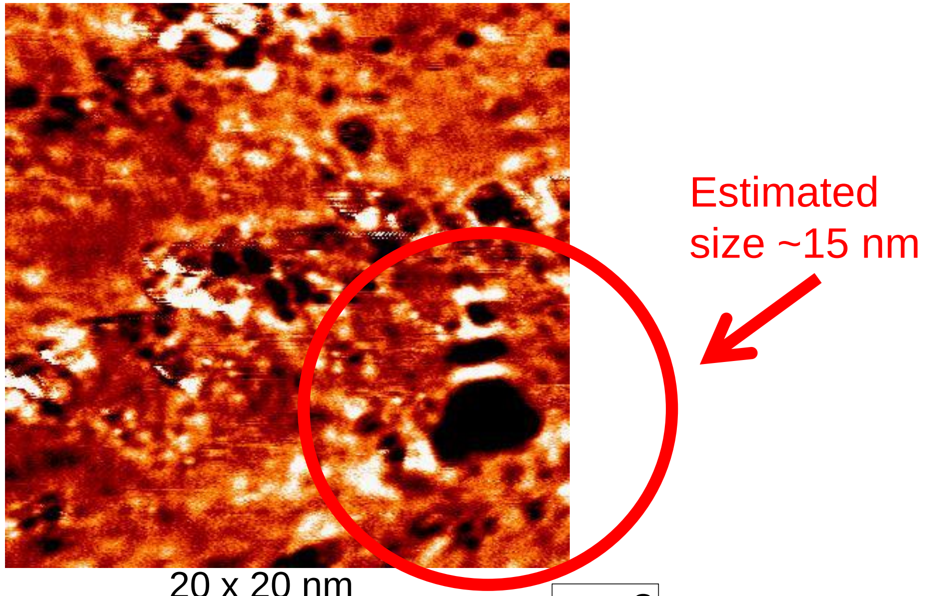


R. Kositski, D. Mordehai / Acta Materialia 90 (2015) 370–379



R. Jacobs, D. Morgan, and J. Booske ArXiv 1712.05308.pdf

Our experiments



20 x 20 nm