What is nano ?

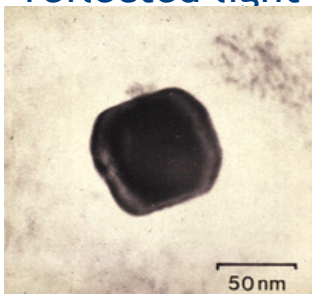
The lycurgus cup (4th century AD in the Bristish Museum)

reflected light

transmitted light

"The Cup is surrounded by a frieze showing the myth of King Lycurgus. He is seen here being dragged into the underworld by Ambrosia, who has been turned into a vine.

The frieze stands out from the body of the Cup, connected to it only by small shanks or bridges. It belongs to a type of Roman glass called cage cups."

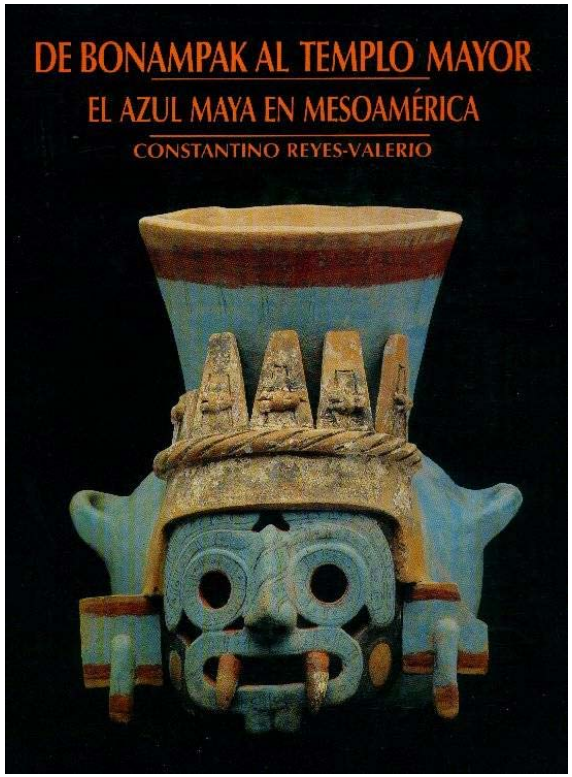


Gold/silver alloy nanoparticles found in the cup by TEM. The color comes from the addition of gold.

From the British Museum website: http://www.thebritishmuseum.ac.uk

What is nano ?

Mayan blue pigments: Indigo encapsulated in clays.



Constantino Reyes-Valerio

Maya Blue Paint: An Ancient Nanostructured Material

M. José-Yacamán,* Luis Rendón, J. Arenas, Mari Carmen Serra Puche

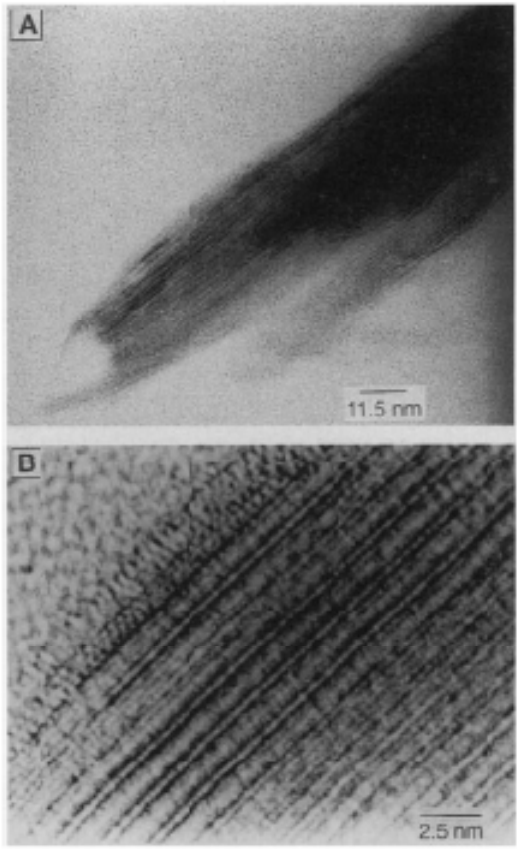


Fig. 3. Palygorskite crystals. (**A**) Needle shape of the crystals. (**B**) High-magnification image of a crystal showing a superlattice period of about 1.4 nm.

Science, **273** (1996) 223-225.

UC SANTA BARBARA
engineering and the sciences

What is nano ?

Gold colloids (sols): The work of Faraday

X. THE BAKERIAN LECTURE.—*Experimental Relations of Gold (and other Metals) to Light.* *By* MICHAEL FARADAY, *Esq., D.C.L., F.R.S., Fullerian Prof. Chem. Royal Institution, Foreign Associate of the Acad. Sciences, Paris, Ord. Boruss. pour le Mérite, Eq., Memb. Royal and Imp. Acadd. of Sciences, Petersburgh, Florence, Copenhagen, Berlin, Göttingen, Modena, Stockholm, Munich, Bruxelles, Vienna, Bologna, Commander of the Legion of Honour, &c. &c.*

Philos. Trans. R. Soc. London **147** (1857) 145-181

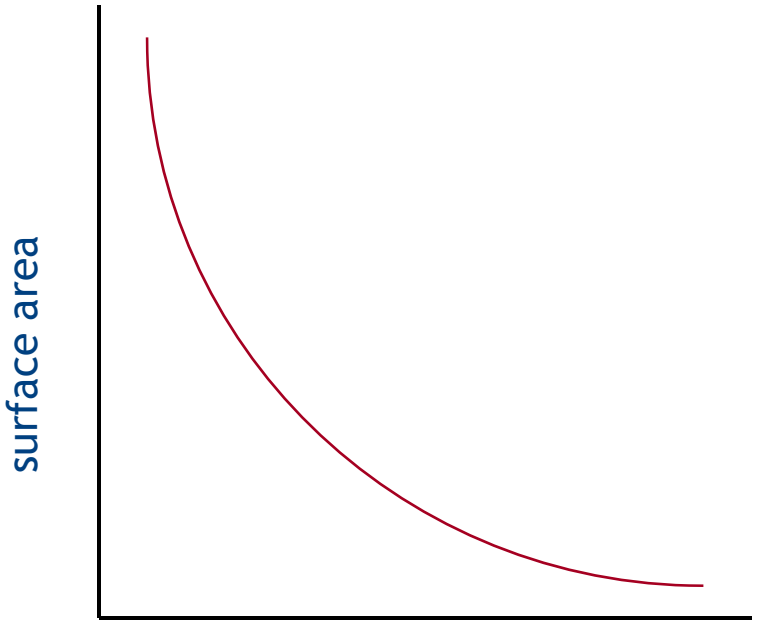
Gold leaf can be beaten to thicknesses of 1/278000 of an inch (around 90 nm). Such films are continuous and green in transmission. Further thinning with KCN gives ruby red films.

Chemical means to finely divided gold. Also deflagration of gold wires to produce ruby red particles. Chemically indistinguishable from gold.

What is nano ?

Nanoparticles in catalysis:

Heterogeneous catalysis takes place on the surfaces of solids



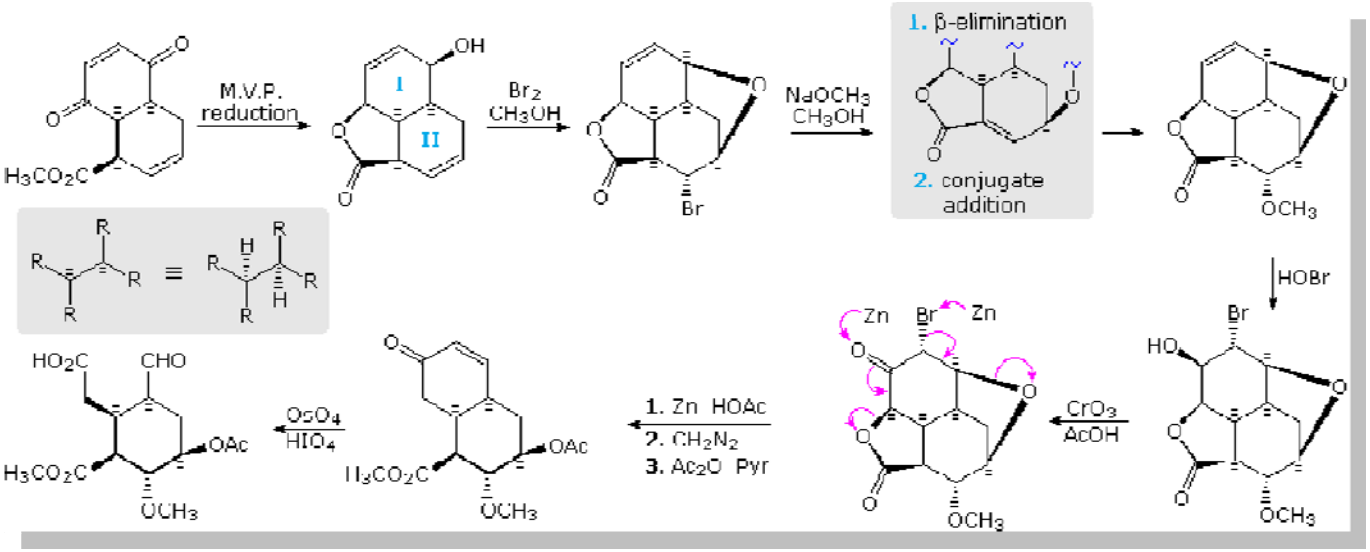
The smaller the particles, the more effective the catalyst. Is this *nano* ?

What is nano ?

Feynman (December 29th 1959 at the annual meeting of the American Physical Society):
"What I want to talk about is the problem of manipulating and controlling things on a small scale . . . But I am not afraid to consider the final question as to whether, ultimately – in the great future – we can arrange the atoms the way we want; the very *atoms*, all the way down! What would happen if we could arrange the atoms one by one the way we want them (within reason, of course; you can't put them so that they are chemically unstable, for example)"

What is nano ?

American chemist best known for his syntheses of complex organic substances, including quinine (1944), cholesterol and cortisone (1951), and vitamin B12 (1971). He was awarded the Nobel Prize for Chemistry in 1965

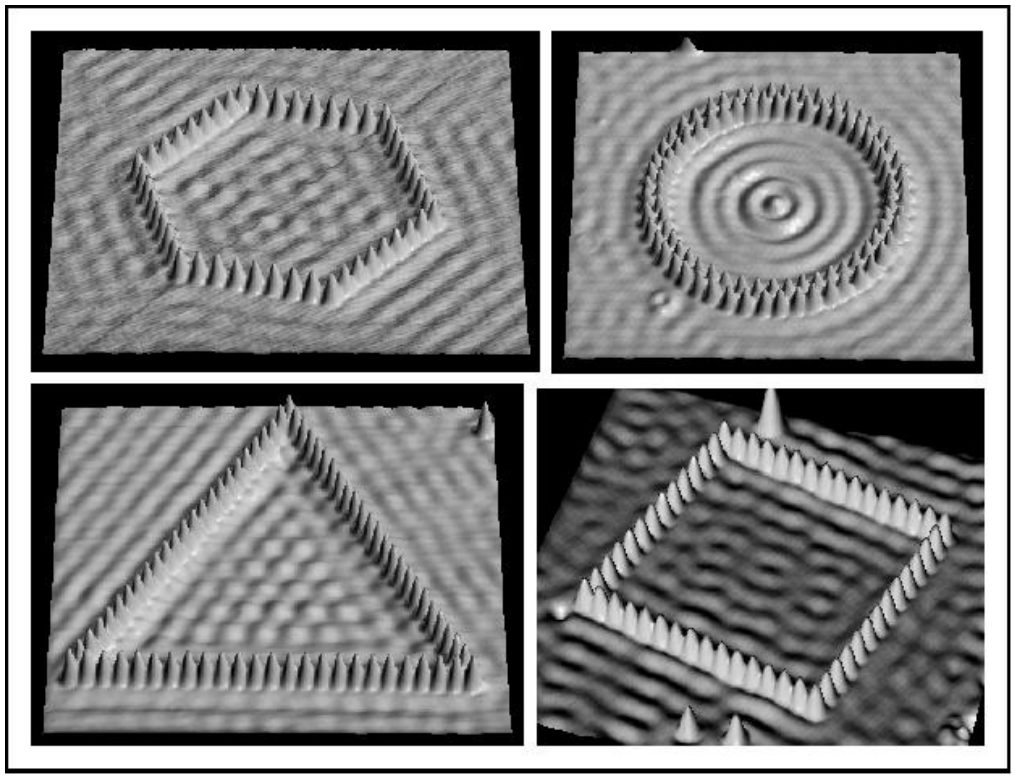


Reserpine total synthesis

Is this what Feynman is talking about ?

What is nano ?

New tools: The scanning tunelling microscope



Fe atoms on Cu.

M. F. Crommie, C. P. Lutz, D. M. Eigler, E. J. Heller. Waves on a metal surface and quantum corrals. *Surface Rev. Lett.* **2** (1995) 127-137.

What is nano ?

New tools: The electron microscope:

Direct Sub-Angstrom Imaging of a Crystal Lattice

P. D. Nellist,[1] M. F. Chisholm,[2] N. Dellby,[1] O. L. Krivanek,[1] M. F. Murfitt,[1] Z. S. Szilagyi,[1] A. R. Lupini,[2] A. Borisevich,[2] W. H. Sides Jr.,[2] S. J. Pennycook[2]*

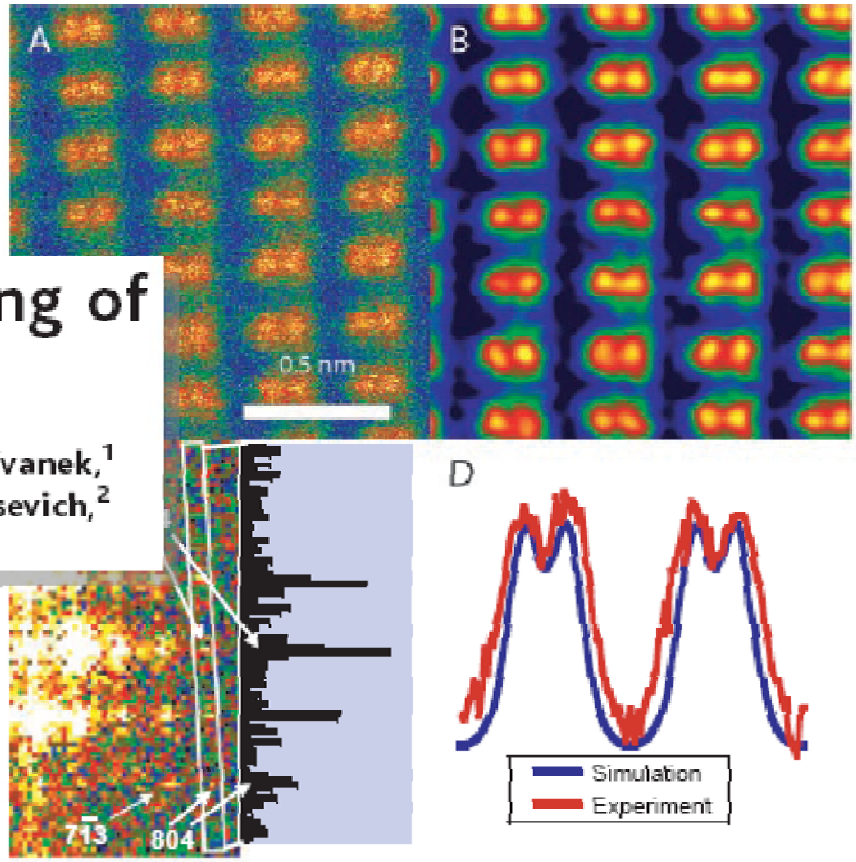


Fig. 1. (A and B) ADF images of Si[112] recorded with an aberration-corrected STEM. The image in (B) has been low-pass filtered to reduce the noise, and the small effects of image drift during the scan have been unwarped. (C) The modulus of the Fourier transform of the image data and a profile through the spots enclosed by the box. The 444 spacing (78 pm) corresponds to the smallest atomic column spacing, and there is information transfer to the 713 (71-pm) spacing and weak transfer at the (804) 61-pm spacing. (D) An intensity profile through two column pairs in (A), formed by summing over a width of 10 pixels. A simulated profile (6) is shown for comparison.

Science **305** (2004) 1741.

What is nano ?

New tools: The electron microscope:

Dopants adsorbed as single atoms prevent degradation of catalysts

SANWU WANG[1], ALBINA Y. BORISEVICH*[2], SERGEY N. RASHKEEV[1], MICHAEL V. GLAZOFF[3], KARL SOHLBERG[4], STEPHEN J. PENNYCOOK[1,2] AND SOKRATES T. PANTELIDES[1,2]

Nature Mater. **3** (2004) 143.

Single La atoms on Al_2O_3.

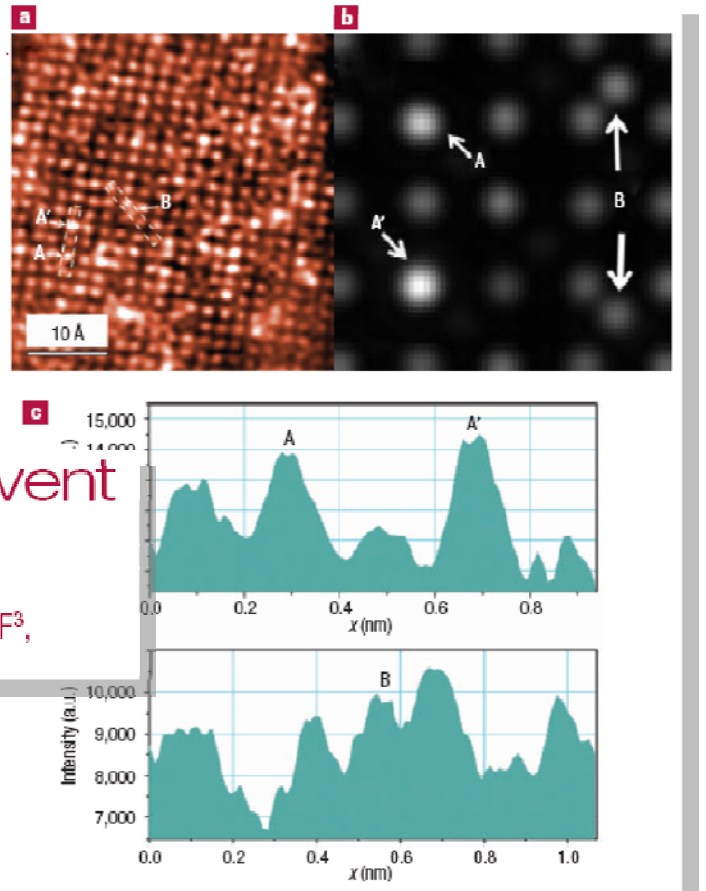
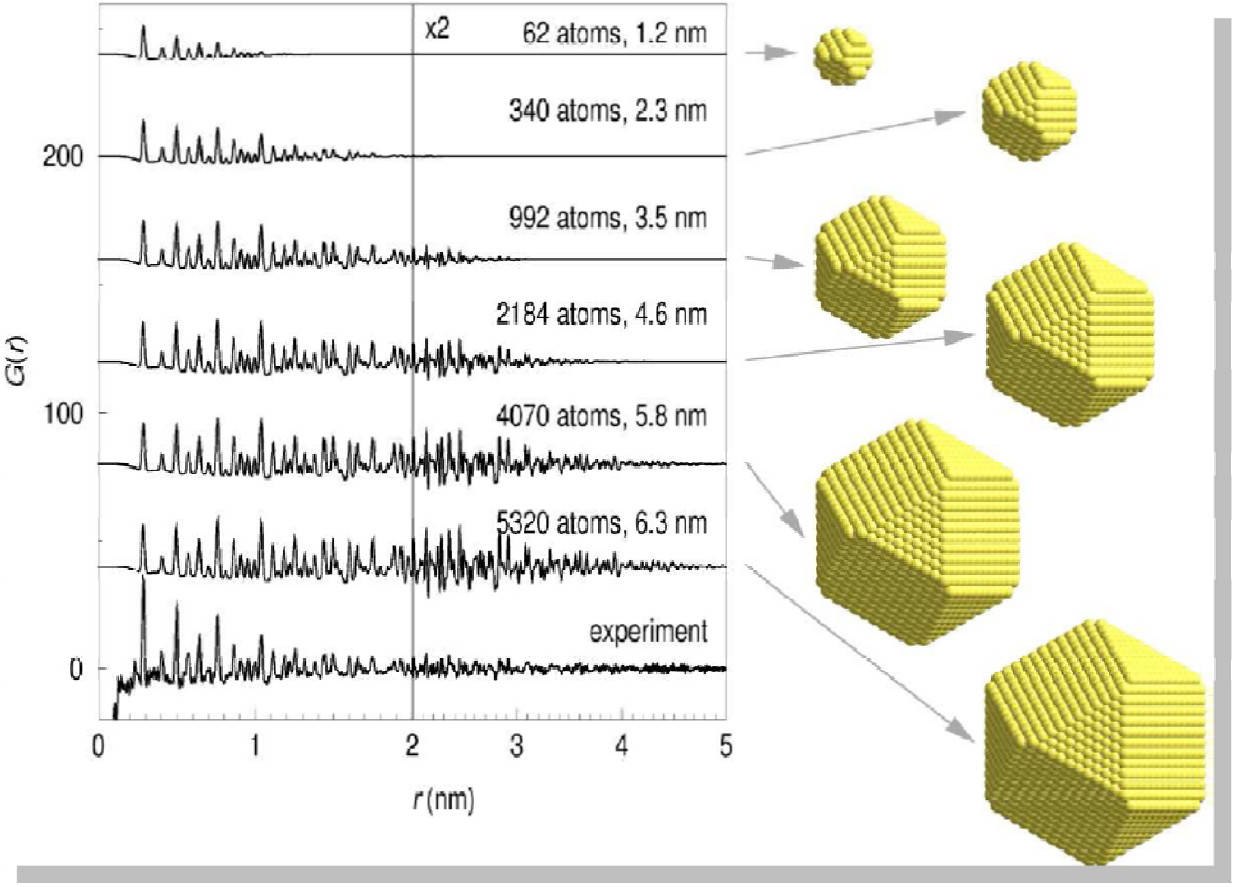
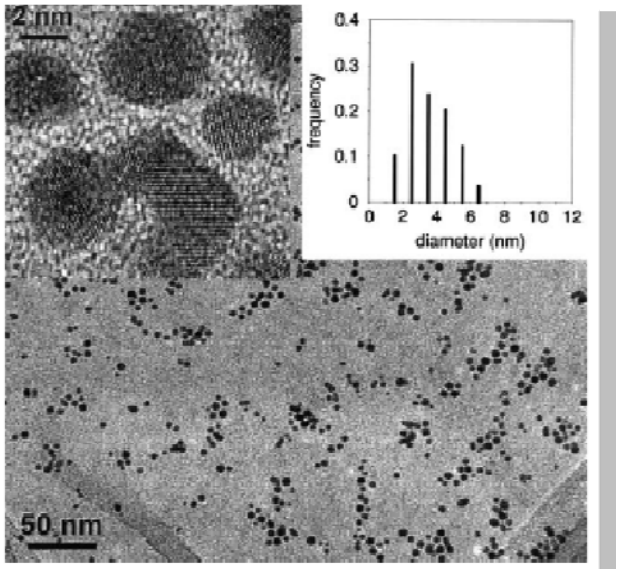


Figure 1 La atoms on g-Al_2O_3 flake in [100] orientation. a, Z-contrast STEM image. Two distinct sites (A(A′) and B) for individual La atoms are seen (images are high- and low-pass filtered). b, Multislice simulation[20] of A, A′ and B positions of La atoms over and under a 40-Å slab of γ-Al_2O_3 at zero defocus for an aberration-free probe of 15 mrad semi-angle; one phonon configuration was found sufficient to achieve convergence. c, Intensity (in arbitrary units, a.u.) profiles of the smoothed raw data corresponding to the line traces denoted on a.

What is nano ?

New tools: Scattering methods.

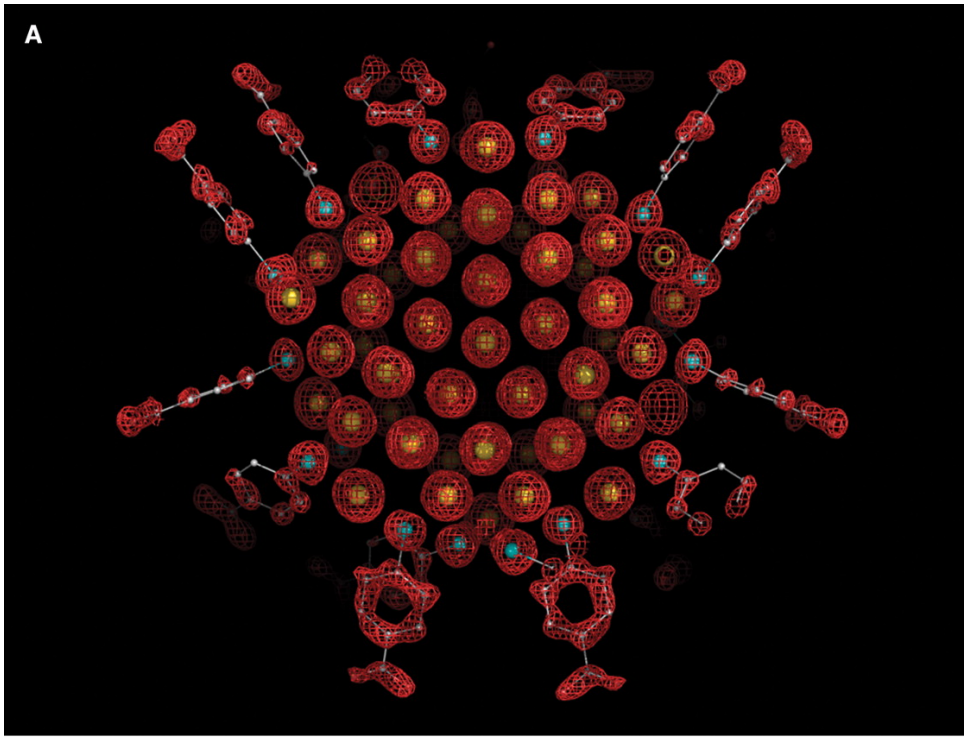


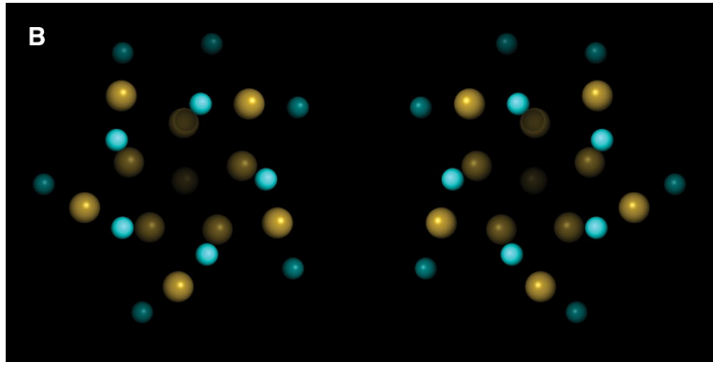


K. Page, T. Proffen, H. Terrones, M. Terrones, L. Lee, Y. Yang, S. Stemmer, R. Seshadri and A. K. Cheetham, Direct Observation of the Structure of Gold Nanoparticles by Total Scattering Powder Neutron Diffraction, *Chem. Phys. Lett*. **393** (2004) 385-388.

What is nano ?

Enter the biochemists.

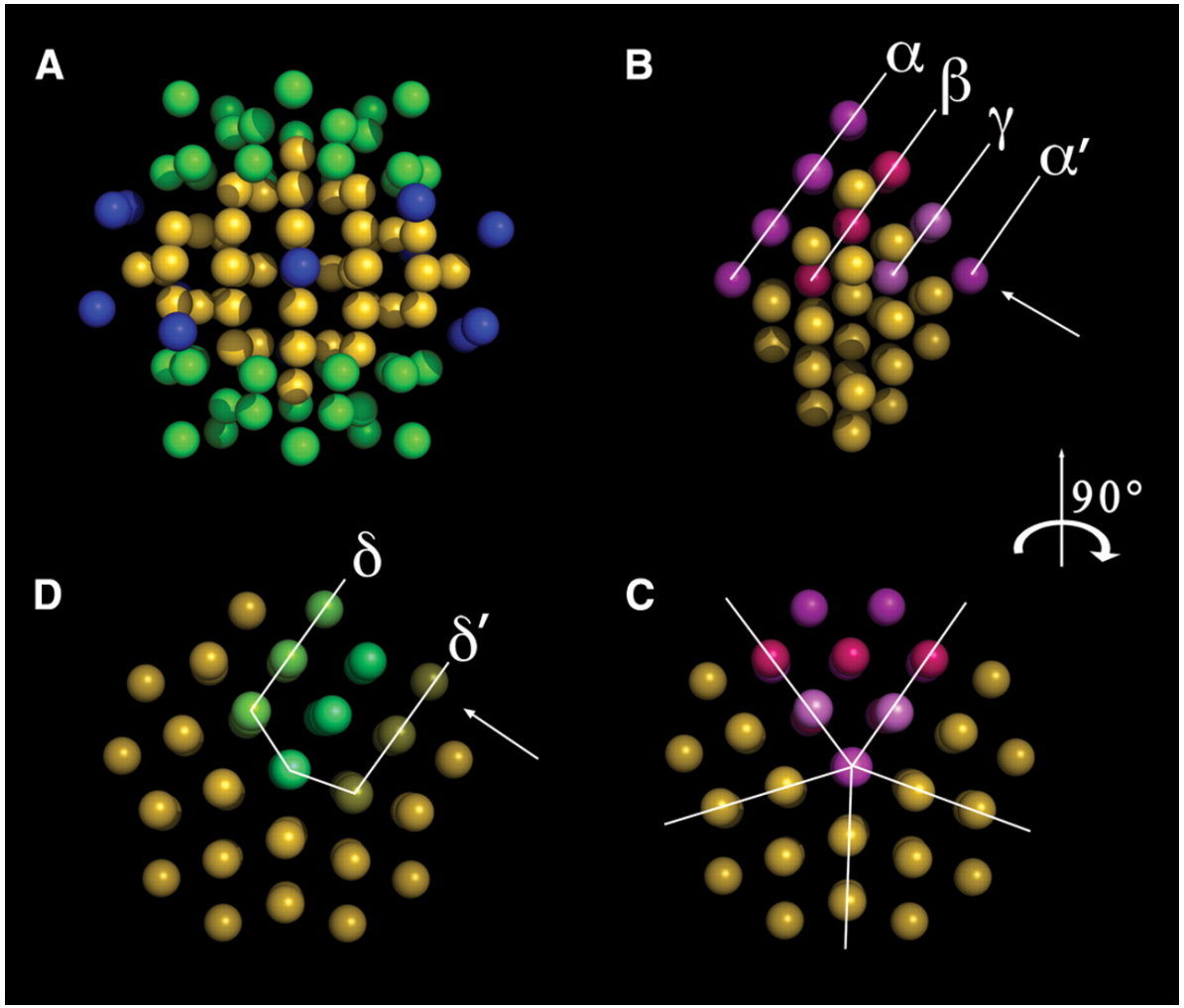




p-mercaptobenzoic (*p*-MBA) acid capped gold nanoparticles: 102 gold atoms, and 44 (*p*-MBA)

Jadzinsky *et al.*, Structure of a thiol monolayer-protected gold nanoparticle at 1.1 A resolution, *Science* **318** (2007) 430-433.

Class 01: Recent breakthroughs in structure and composition 1: The nanostructure problem



Many ways of looking at the gold core, including as 5 twinned *fcc* units seen in C.

Jadzinsky *et al.*, Structure of a thiol monolayer-protected gold nanoparticle at 1.1 A resolution, *Science* **318** (2007) 430-433.

What is nano ?

New tools: Computational methods.

A. Maiti, C. J. Brabec, C. Roland, and J. Bernholc, Theory of carbon nanotube growth, *Phys. Rev. B* **52** (1995) 14850.

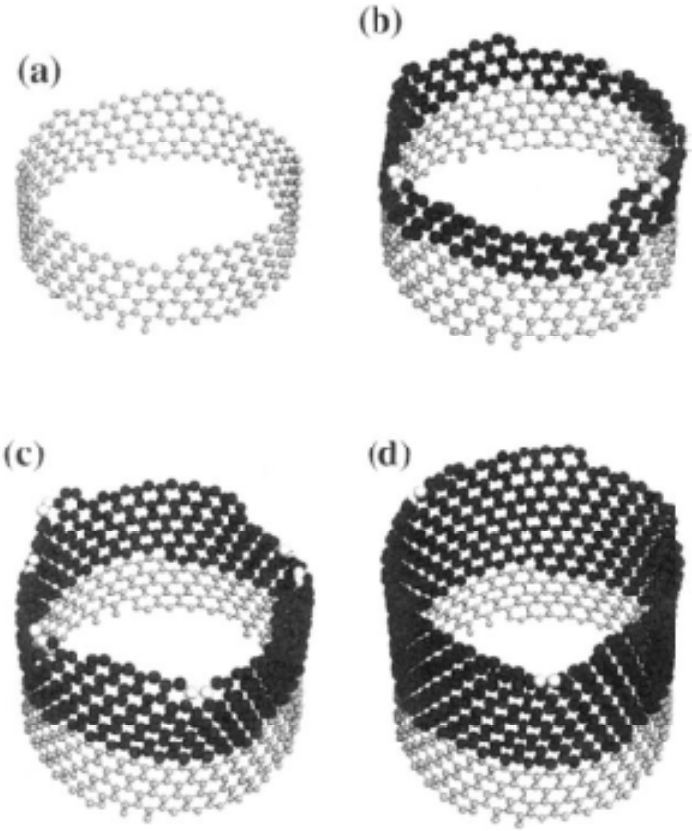
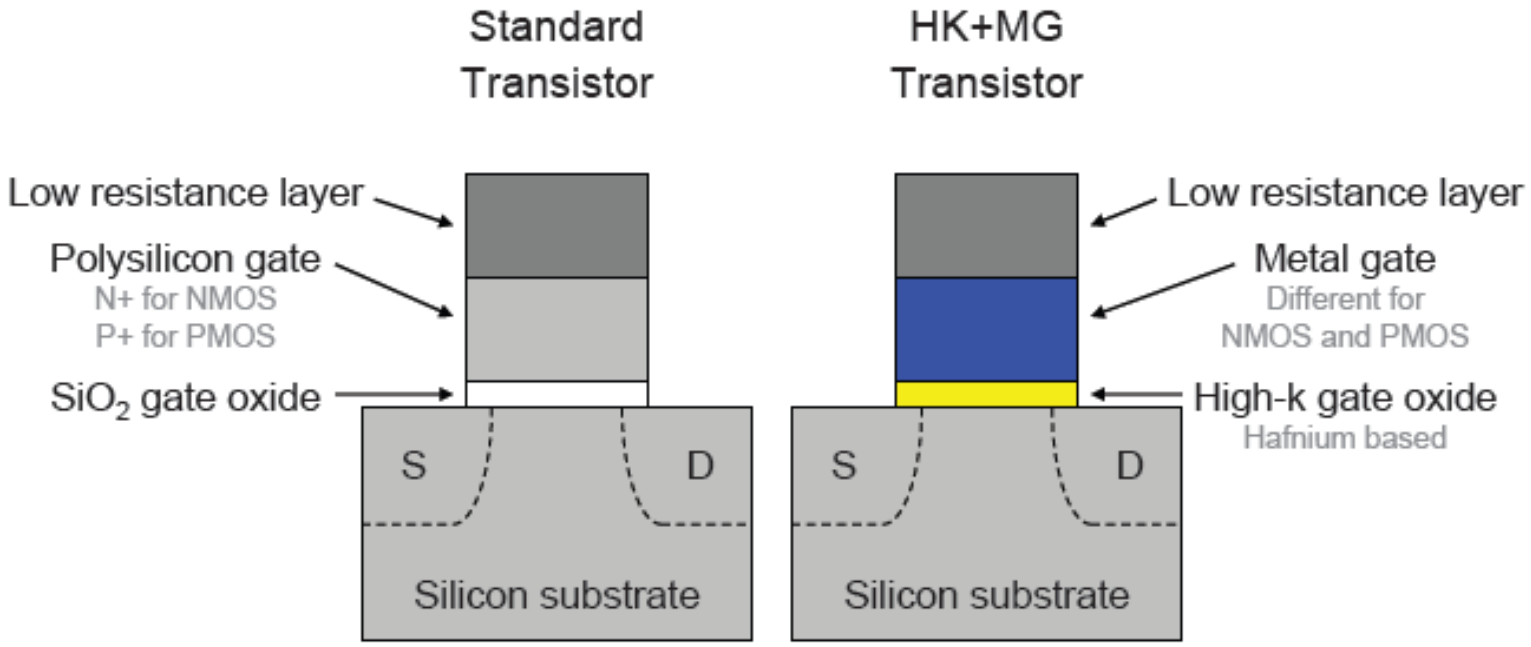


FIG. 9. A growth sequence of a 3-nm-wide tube of helicity (35,5): (a) the initial all-hexagonal tube; (b) after the addition of 200 atoms; (c) after 400 atoms; and (d) after 600 atoms. The number of pentagons and heptagons are 3 and 1 in (b), 5 and 1 in (c), and 1 and 1 in (d), respectively. Their positions are high lighted by the lighter atoms at the tube tips.

What is nano ?

New tools: High integration in computer chips

Intel's 45 nm technology in Penryn chips.



What is nano ?

New tools: High integration in computer chips

Intel's 45 nm technology in Penryn chips.