Nanoscience and Technology

Nanoscience and technology (NST) is not a new subject area. Rather, it reflects a new emphasis, that of the theory, tools, and technique for designing and controlling processes and devices on the submicrometer or nanometer scale, smaller than the wavelength of visible light. This interdisciplinary field has been brought about primarily by the drive to smaller transistors on computer chips and by instrumentation developed in the 1980's that allows the imaging and manipulation of individual atoms. There are two main approaches to NST, "top down" and "bottom up".

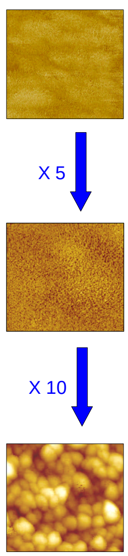
Top Down

"Top down" implies a continuation of present day technology, building devices that are smaller, faster, and less expensive by refining current fabrication methods. The computer industry has long pursued top-down technology by making ever more powerful and affordable integrated circuits.

Bottom Up

"Bottom up" implies increasing our knowledge of the chemical and physical properties of molecules such that we can purposefully design systems in which a desired pattern or product assembles itself. Life, from single-celled animals to humans, is the inspiration for bottom-up approaches.

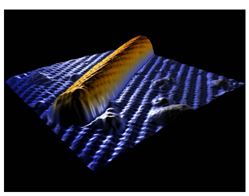
Size Scales and Self-Assembly

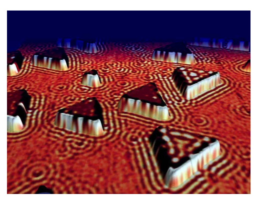


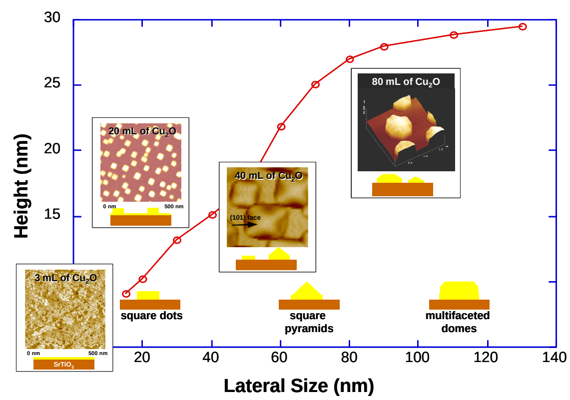
One of the fascinating aspects of NST is how apparently flat objects seem so rough on a small scale. To the left is an image of an apparently smooth surface, approximately twenty microns on a side. (Twenty microns is about as well as you can see with a hobbyist's optical microscope.) Increasing the magnification by five, one starts to observe some roughness. A further ten times higher in magnification shows discrete nodules, approximately twenty nanometers in diameter. A nanometer is one-thousand of a micron. (Pasquini et al., IMGC-CNR and UNITO, Italy)

Below left, the atoms on the surface of silicon become visible at still higher magnification (blue shading). The pencil-like object is a carbon nanotube. (Albrecht, Illinois)

Below right, at even higher magnification, the standing waves of copper electrons due to reflection from two-atom high triangular cobalt islands. (Wiesendanger Group, Hamburg)



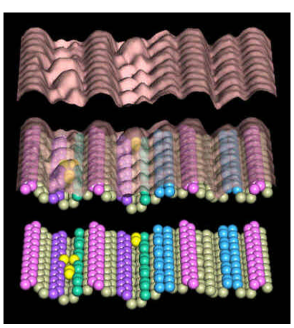




The forces of nature can cause inanimate objects to self-assemble into striking patterns, as shown above, in which more and more copper oxide is deposited onto a flat substrate. Depending on the amount of copper oxide available, the pattern shifts from square dots to square pyramids to multifaceted domes.

Liang et al., Pacific Northwest National Lab

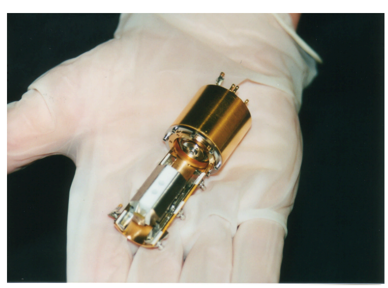
Theory



Theorists match experimental data (top, silicon surface observed with a scanning tunneling microscope) with models (bottom, each ball represents an atom) to see how well they understand the data.

Baski, Erwin, Whitman, Naval Research Lab

Tools



The essential components of a scanning tunneling microscope, one of the most important tools in nanoscience, in the hand of its designer.

Hersam, Northwestern University

Technique

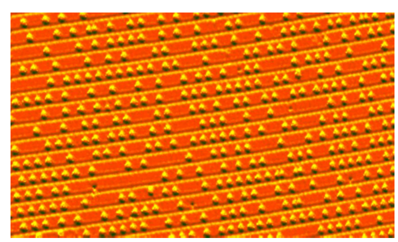


Image of an atomic memory made from the self-assembly of silicon atoms onto a specially prepared silicon substrate. The presence or absence of atoms represent the 1s and 0s of a digital memory. The storage density is approximately a million times that of a CD.

Bennewitz et al., Nanotechnol. **13**, 499 (2002)

Nanoscience has the potential to fundamentally change technology according to well-understood physical laws.

Right image – AVS 50th Anniversary logo written into ferroelectric material in an area twenty microns on a side. (Kalinin and Bonnell, Penn)

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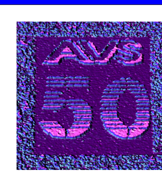

Graphic by L.J. Whitman, NRL