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Office of Public Affairs
111 TASF
Ames, IA 50011-3020
http://www.ameslab.gov

Contacts:
Michael C. Tringides, Condensed Matter Physics,
(515) 294-6439, tringides@ameslab.gov
Saren Johnston, Public Affairs, (515) 294-3474, sarenj@ameslab.gov

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AMES LAB PHYSICISTS FIND UNUSUAL GROWTH MODE AT LOW TEMPERATURE

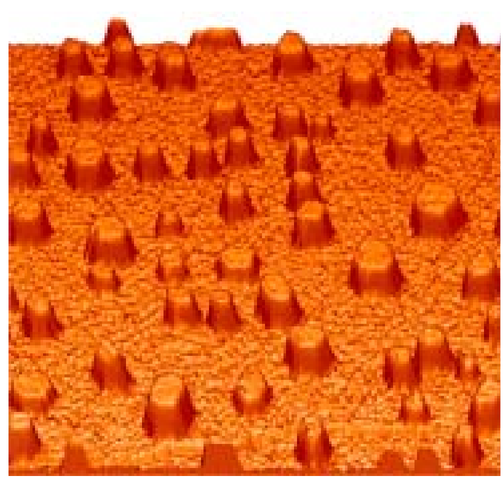
Discovery Leads to Novel Ways to Control Growth of Uniform Atomic-scale Structures

AMES, IA – "Control is the name of the game," said Ames Laboratory physicist Michael C. Tringides. He was talking about the importance of growing atomic structures and ultrathin metal films in uniform sizes and with highly ordered geometries for technological applications that include switches, lasing materials and semiconductors that allow computer chips to run faster.

Exciting as the potential is for the development of these nanotechnologies (artificially fabricated structures in the nanometer range of 0.1-100 nm) and other microminiature equipment, Tringides knows that realizing such applications requires laying substantial groundwork. He and members of his research group, associate scientist Myron Hupalo and graduate students Vincent Yeh and Michael Yakes, are doing basic research at the U. S. Department of Energy's Ames Laboratory to learn more about the microscopic processes that control the growth of custom-made materials. The work, supported by the DOE's Office of Basic Energy Sciences, may prove critical in the further miniaturization of silicon-based electronic devices, a major undertaking in light of the silicon industry's huge role in technological innovation and production.

Tringides explained that vital to the success of these miniaturization efforts is the ability to achieve exact control of layer thickness and atomic uniformity of thin films and nanostructures – what he refers to as "the 'Holy Grail' in nanotechnology, the next major industrial revolution."

Noting the great demand for these materials within the silicon industry, Tringides said, "It's essential that these structures are grown in a robust and reproducible way, with easy size selection. Contrary to conventional wisdom, we've discovered that an intriguing type of self-organization is possible with lead (Pb) deposited on silicon (Si) if the growth is carried out at low temperature – around 185 Kelvin, or minus 126 degrees Fahrenheit." He added that in all other systems studied so far, the deposited metal atoms stack up in islands of very wide height variation. But for Pb grown on Si (oriented along the (111) crystal axis), he said the atoms seem to be "intelligent" and make only one height choice.



This image of the Pb/Si(111) islands shows that the majority of the islands are seven layers high.

"The selected height of these nanostructures is related to their electronic structure," Tringides continued. He explained that keeping electrons confined in small metal islands requires them to occupy sharp energy levels as dictated by the laws of quantum mechanics. This confinement implies that the total energy of the electrons depends strongly on the nanostructure's size or shape. "This is called Quantum Size Effects, or QSE," said Tringides, "and a consequence of this relationship is that certain film thicknesses are more stable than others."

Tringides and his research group were the first to observe and monitor the highly unusual formation of uniform-height Pb /Si islands. They observed the 7-step, steep-edged, flat-top islands using two complementary techniques. Quantitative electron diffraction, used by Yeh and Yakes, samples the island height uniformity by reflecting electron waves from the surface. Scanning tunneling microscopy (STM), used primarily by Hupalo, images the islands as they form, giving the island size and shape. "As a result of our investigations, we have shown that not only can QSE be observed in small objects, but QSE can dictate the island uniformity and height," said Hupalo.

The scientists were amazed to see this uncommon growth mode of the 7-step Pb islands, which clearly shows that the deposited atoms seem able to "climb" and select preferred, final positions. "No one was expecting to see the uniform-height, self-organized growth," said Tringides. "We couldn't believe how quickly the islands formed following deposition. Nature, itself, was doing the work for us!"

Tringides explained that although QSE is the driving force for height uniformity, one still needs to find the right temperature and surface coverage conditions for the islands to form. These variables make it difficult to predict when the self-organized growth is possible and explain why it has never been seen before.

"It's necessary to study the growth as a function of the different growth parameters, such as temperature and deposition rate, to discover when such self-organized nanostructures form," said Tringides. By varying these parameters in the Pb/Si(111) system, he and his co-workers found that only odd heights, i.e. 5-, 7-, and 9-step-high islands, are possible. Using these growth parameters, they developed a kinetic phase diagram that serves as a guide to select the desired island height.

But Tringides warned that island height uniformity exists only at sufficiently low temperature. At higher temperature, the islands evolve into multiheight mounds, limiting their potential for room-temperature applications. Working to resolve the problem, Tringides and members of his research group have discovered that they can "manipulate the growth" by adsorbing oxygen, which restricts the upward motion of the Pb atoms, allowing the islands to maintain the same height. This process extends their stability to higher temperature and their potential for technological applications.

Ames Laboratory is operated for the DOE by Iowa State University. The Lab conducts research into various areas of national concern, including energy resources, high-speed computer design, environmental cleanup and restoration, and the synthesis and study of new materials. More information about the Ames Laboratory can be found at www.ameslab.gov.

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Note to Editors: For an image file of the Pb/Si(111) islands on the front, go to:
http://www.external.ameslab.gov/news/release/2004rel/leadsiliconimage.htm