Nanoscale materials grow with the flow (Videos)

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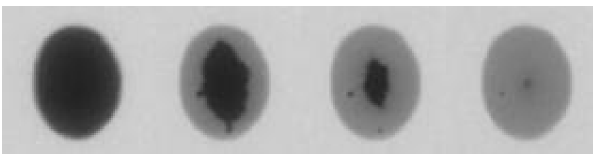

Lead atoms in liquid-like motion across a silicon substrate. The black region is an area initially without lead, and the outside white area has a full layer of lead. The four images represent snapshots of how the outside layer moves and fills the empty area. (The difference in grey and white is because the new lead atoms that enter the empty area are not yet in their perfect sites.) US Department of Energy Ames Laboratory scientists, in collaboration with scientists from Hong Kong University of Science and Technology, were the first to observe this unique diffusion of lead atoms on a silicon substrate. Credit: US Department of Energy's Ames Laboratory

Imagine unloading a pile of bricks onto the ground and watching the bricks assemble themselves into a level, straight wall in only a few minutes. While merely a fantasy for builders in the everyday world, these types of self-assembled structures are a reality for those who build materials in the nanoworld. Michael C. Tringides, a senior physicist at the U.S. Department of Energy's Ames Laboratory, has shown that nanoscale "straight wall" lead islands on silicon are spontaneously and quickly created by unusually mobile atoms.

Several years ago, Tringides' research group was the first to observe that lead atoms deposited on a silicon surface at low temperatures self-organize into uniform-height island nanostructures. The laws of quantum mechanics - specifically, Quantum Size Effects - determine why lead atoms stack up to create uniform islands while other nanostructure systems organize into islands that vary in height.

How the lead-on-silicon islands organized into uniform-height islands remained a mystery until Tringides' team made the surprising discovery that when lead atoms move along the surface of a silicon substrate, the lead atoms exhibit a liquid-like motion instead of the typical random-type diffusion observed in other systems. The liquid-like motion of atoms was observed using scanning tunneling microscopy at Ames Lab and low energy electron microscopy performed by collaborators in Hong Kong.

"One big surprise was that the atoms were moving a lot at such a low temperature: 150 degrees Kelvin or minus 123 degrees Celsius," said Tringides. "The other surprise was that the atoms weren't moving randomly like individual atoms as we would expect. In this particular case, it seemed like the whole layer of lead atoms was moving like a liquid.

Fluid-like motion of the lead atoms explains why the layer moves so easily and forms uniform islands so quickly.

"When applying nanotechnology, it's very important to be able to make nanostructures of the same dimension using a method that others can easily replicate," said Tringides. "And, it's important that the growth process is fast."

Tringides' work succeeds in terms of uniformity and speed. The lead islands self-organize on silicon in only two to three minutes. Also, better understanding of how the lead islands grow will help researchers see if other systems show the same liquid-like behavior at low temperatures.

With such promising findings in hand, Tringides' team, which includes associate scientist Myron Hupalo and graduate students Steven Binz and Jizhou Chen, further investigated the possible use of these unusual lead islands on silicon as templates to study typical atomic processes, such as adsorption, nucleation and atom bonding. These processes are important in the study of reactivity and catalysis.

During those experiments, Tringides' group made another unexpected discovery. Normally atomic processes depend on an element's chemical nature, but the group found that when it came to lead islands, quantum mechanics had another surprise in store: The atomic processes depend dramatically on whether the island height is odd or even rather than its chemical nature. Tringides' group made this intriguing observation in a large lead island that had formed over a step on the original silicon surface. The top of the large island was flat as expected.

"But, the part of the island sitting on the higher terrace of silicon was four layers high, and the other part of the island sitting on the lower terrace was five layers," said Tringides.

The group studied nucleation on this unusual island by adding a very small amount of lead to its surface, creating many new small islands on top of the large island. Examination revealed that the density of the new islands was 60 times higher on the four-layer part of the island than on the five-layer part even though the two parts of the island were connected, suggesting that atom bonding is easier on the four-layer islands.

"The island was made up of the same element, lead, throughout," said Tringides. "So, we would expect the two parts of the island to communicate with each other, and atoms should be able to easily move from left to right and right to left among both halves of the island, so the density of the new small islands should have been the same in both parts."

Instead, the two halves of the island behaved like two separate islands. The four-layer section of the island has similar characteristics to independent four-layer islands, and the five-layer section behaved like other five-layer islands.

"For the purpose of growing materials, the two-part island indicates that we may not have to change the element to create variation in material properties," said Tringides. "Instead, we may be able to just change the height of the island."

"This is promising because it's easier to change the geometry of an island than to go out and find a new, exotic material," he added.

Tringides plans further experiments using gas adsorption to test the relationship between material reactivity and island height.

Source: Ames Laboratory

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