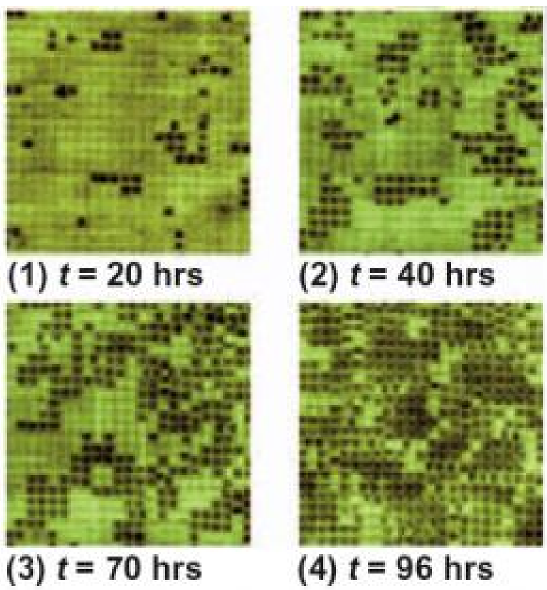
Watching crystals grow provides clues to making smoother, defect-free thin films

January 21 2010, By Anne Ju

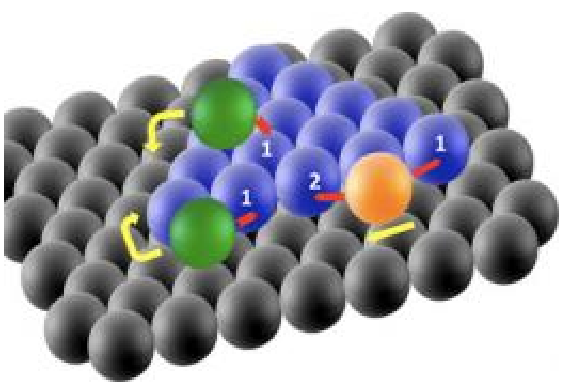


Four images from different points in time during an island growth experiment. Image: Itai Cohen group

(PhysOrg.com) -- To make thin films for semiconductors in electronic devices, layers of atoms must be grown in neat, crystalline sheets. But while some materials grow smooth crystals, others tend to develop bumps and defects - a serious problem for thin-film manufacturing.

In the online edition of the journal *Science* (Jan. 22, 2010), Cornell researchers shed new light on how atoms arrange themselves into thin films. Led by assistant professor of physics Itai Cohen, they recreated conditions of layer-by-layer crystalline growth using particles much bigger than atoms, but still small enough that they behave like atoms.

"These particles are big and slow enough that you can see what's going on in real time," explained graduate student Mark Buckley.
Using an optical microscope, the scientists could watch exactly what their "atoms" - actually, micron-sized silica particles suspended in fluid - did as they crystallized. What's more, they were able to manipulate single particles one at a time and test conditions that lead to smooth crystal growth. In doing so, they discovered that the random darting motion of the particles is a key factor that affects how the crystals grow.



Schematic of atoms diffusing on and near a crystal island. The green particles are encountering an edge or corner, where they find a barrier. The orange particle encounters smaller barriers as it moves from site to site. The 1 indicates the bond being broken. The 2 indicates a bond that is forming. Near an edge or corner, the atoms do not have a new neighbor to form a bond with, which is what creates the barrier. Image: Itai Cohen group

A major challenge to growing thin films with atoms is that the atoms often form mounds, rather than crystallizing into thin sheets. This happens because as atoms are deposited onto a substrate, they initially form small crystals, called islands. When more atoms are dumped on top of these crystals, the atoms tend to stay atop the islands, rather than hopping off the edges - as though there were a barrier on the crystals' edges. This creates the pesky rough spots, "and it's game over" for a perfect thin film, Cohen said.

Conventional theory says that atoms that land on top of islands feel an energetic "pull" from other atoms that keeps them from rolling off. In their colloidal system, the researchers eliminated this pull by shortening the bonds between their particles. But they still saw that their particles hesitated at the islands' edges.

Further analysis using optical tweezers that manipulated individual particles allowed the researchers to measure just how long it took for particles to move off the crystal islands.

Because the particles were suspended in a fluid, they were knocked about in what's called Brownian motion, which is like a random walk.

As the particles moved and diffused from one area to another, the researchers noted that the distance a particle had to travel to "fall" off an island's edge was three times farther than moving laterally from one site on the island to another.

And because the particles had to go this distance in a Brownian fashion, it took them nine times longer to complete this "fall." This difference in time explained why the researchers still saw a barrier at their island edges.

Video: Using a solution of tiny plastic spheres 50 times smaller than a human hair, scientists at Cornell University discovered the thin, smooth crystalline sheets needed to make semiconductors can be grown more smoothly by managing the random darting motions of the atomic particles *that affect how the crystals grow. Researchers reproduced the conditions that lead to crystallization on the atomic scale by using particles much bigger than atoms, but still small enough that they behave like atoms to watch how particles crystallize. Additionally, with special laser beams known as "optical tweezers," researchers placed an individual particle (atom) on top of a growing crystal island and determined how easy it was for the particle to hop off that island. They found the random darting motions of a particle are a key factor that determines how long it spends on the island. When particles can hop off islands more easily, smooth crystals can be grown. Here a colloidal crystal freezes onto a square lattice template. The video is sped up by a factor of about 20. Credit: John Savage, Rajesh Ganapathy, and Itai Cohen*

Atoms on a crystalline film move in a manner similar to Brownian particles, since the vibrations of the underlying crystal, called phonons, tend to jostle them about. The researchers surmised that in addition to the bonding between the atoms, this random motion may also contribute to the barrier at the crystals' edges, and hence the roughness in the crystal film.

"If the principles we have uncovered can be applied to the atomic scale, scientists will be able to better control the growth of thin films used to manufacture electronic components for our computers and cell phones," Cohen said.

Provided by Cornell University

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