Researchers use 'spin coating' to prevent cracking in nanoparticle films

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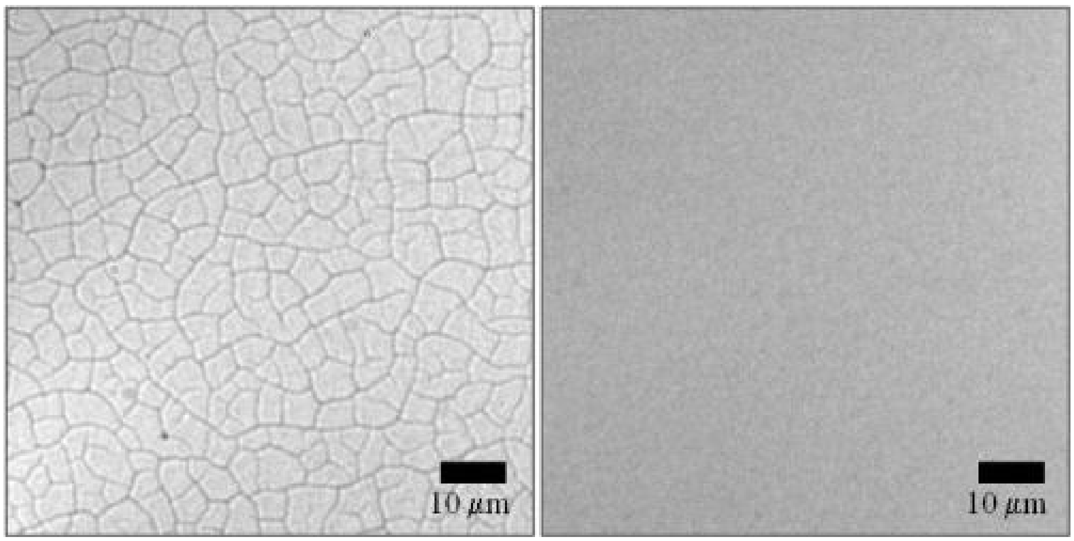

Nanoparticle films crack at certain thicknesses (left). By adding layers of thinner films, cracking can be avoided (right).

(Phys.org)—Making uniform coatings is a common engineering challenge, and, when working at the nanoscale, even the tiniest cracks or defects can be a big problem. New research from University of Pennsylvania engineers has shown a new way of avoiding such cracks when depositing thin films of nanoparticles.

The research was led by graduate student Jacob Prosser and assistant professor Daeyeon Lee, both of the Department of Chemical and Biomolecular Engineering in Penn's School of Engineering and Applied

Science. Graduate student Teresa Brugarolas and undergraduate student Steven Lee, also of Chemical and Biomolecular Engineering, and professor Adam Nolte of the Rose-Hulman Institute of Technology participated in the research.

Their work was published in the journal Nano Letters.

To generate a nanoparticle film, the desired particles are suspended in a suitable liquid, which is then thinly and evenly spread over the surface through a variety of physical methods. The liquid is then allowed to evaporate, but, as it dries, the film can crack like mud in the sun.

"One method for preventing cracking is modifying the suspension's chemistry by putting binding additives in there," Prosser said. "But that is essentially adding a new material to the film, which may ruin its properties."

This dilemma is highlighted in the case of electrodes, the contact points in many electrical devices that transfer electricity. High-end devices, like certain types of solar cells, have electrodes composed of nanoparticle films that conduct electrons, but cracks in the films act as insulators. Adding a binder to the films would only compound the problem.

"These binders are usually polymers, which are insulators themselves," Lee said. "If you use them, you're not going to get the targeted property, the conductivity, that you want."

Engineers can prevent cracks with alternative drying methods, but these involve ultra-high temperatures or pressures and thus expensive and complicated equipment. A cheap and efficient method for preventing cracks would be a boon for any number of industrial processes.

The ubiquity of cracking in this context, however, means that researchers know the "critical cracking thickness" for many materials. The breakthrough came when Prosser tried making a film thinner than this threshold, then stacking them together to make a composite of the desired thickness.

"I was thinking about how, in the painting of buildings and homes, multiple coats are used," Prosser said. "One reason for that is to avoid cracking and peeling. I thought it could work for these films as well, so I gave it a try."

"This is one of those things where, once you figure it out," Lee said, "it's so obvious, but somehow this method has evaded everyone all these years."

One reason this approach may have remained untried is that it is counterintuitive that it should work at all.

The method the researchers used to make the films is known as "spin-coating." A precise amount of the nanoparticle suspension—in this case, silica spheres in water—is spread over the target surface. The surface is then rapidly spun, causing centrifugal acceleration to thin the suspension over the surface in a uniform layer. The suspension then dries with continued rotation, causing the water to evaporate and leaving the silica spheres behind in a compacted arrangement.

But to make a second layer over this first, another drop of liquid suspension would need to be placed on the dried nanoparticles, something that would normally wash them away. However, the researchers were surprised when the dried layers remained intact after the process was repeated 13 times; the exact mechanism by which they remained stable is something of a mystery.

"We believe that the nanoparticles are staying on the surface," Lee said, "because covalent bonds are being formed between them even though we're not exposing them to high temperatures. The inspiration for that hypothesis came from our colleague Rob Carpick. His recent *Nature* paper was all about how silica-silica surfaces form bonds at room temperature; we think this will work with other kinds of metal oxides."

Future research will be necessary to pin down this mechanism and apply it to new types of nanoparticles.

More information: pubs.acs.org/doi/abs/10.1021/nl302555k

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