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# UCLA Engineer


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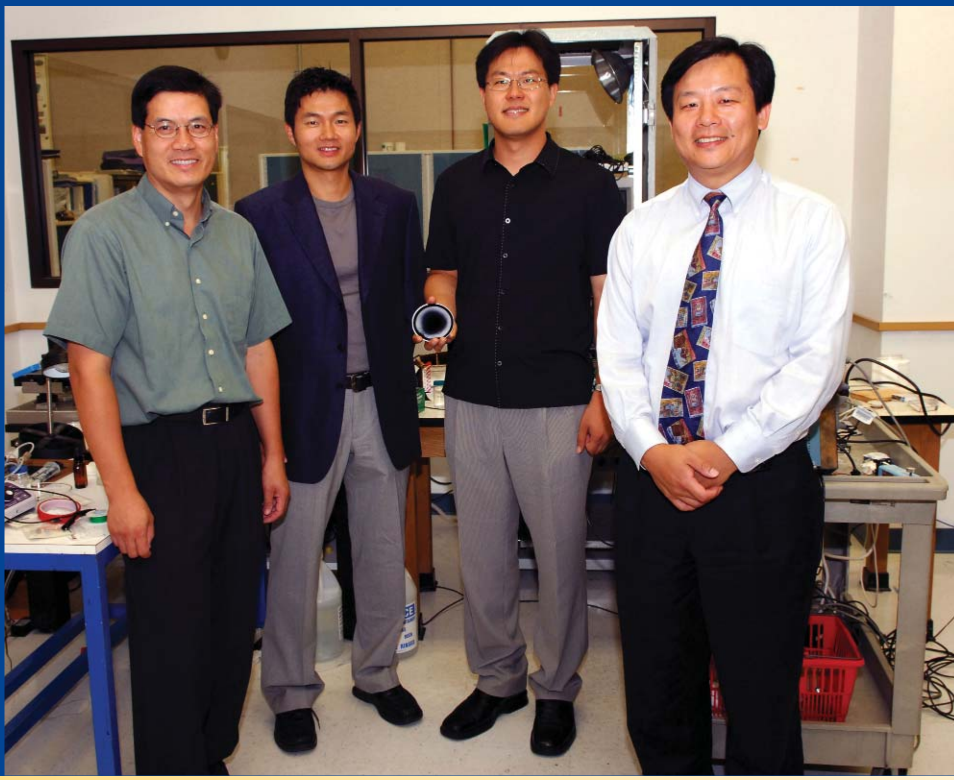
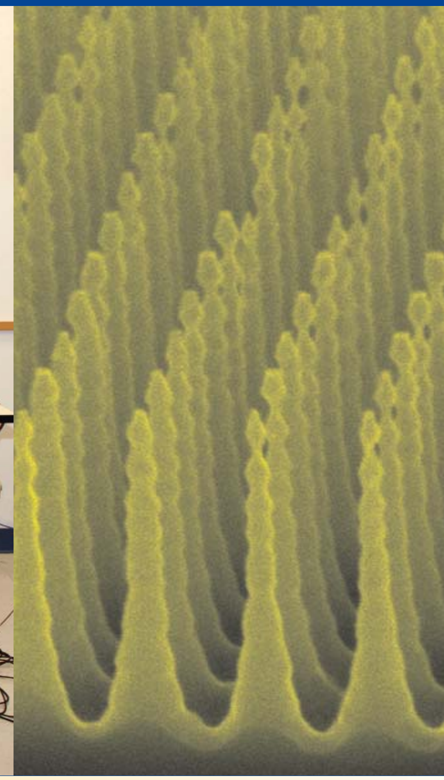
**Developing Tools for Space Exploration**
Engineers Create Handheld Blood Test Unit

**No-slip Condition at the Nanoscale**
Breakthrough Focuses Attention on Fluid Behavior

Don Liebig, UCLA Photography.

(From left) Professor Benjamin Wu, Professor CJ Kim, Chang-Hwan Choi, and Professor James Dunn.

# Researchers Discover No-slip Condition Does Not Hold at the Nanoscale

## New Surface Benefits Microfluidic Applications and Cell Studies

BY MARLYS AMUNDSON

UCLA engineers working on the development of a new ultra-slippery nano-engineered surface have challenged a long-held concept in fluid dynamics—the no-slip condition. Mechanical and aerospace engineering professor CJ Kim and graduate student Chang-Hwan Choi have proven that their nano-architectured surface in effect defeats the fundamental notion of no-slip by a considerable margin, even in practical flow conditions.

The no-slip condition states that fluids stick to surfaces past which they flow, and there is no movement where a fluid touches the surface of a solid. Most challenges to this condition thus far have come from scientific interests because the amount of measurable slip has been too small to be useful. The advent of micro and nano technologies, however, has refocused attention on slip flows and the need to measure slip accurately because microfluidic applications can be affected by even a relatively small slip.

Since the amount of drag reduction caused by the internal slip surface of a pipe is determined by pipe size and flow conditions as well as the surface itself, a rather complex scientific value called *slip length* should be used to objectively describe the slip as a pure surface property, according to Kim.

Until recently, most of the reported slip lengths were less than one micrometer and prone to measurement errors. Kim and Choi expected to measure tens of micrometers of slip length on their new surface, and so considered a slip of less than one micrometer as no slip. "We started with the no-slip assumption on a flat surface in testing our slip length," said Choi, "and in most instances it remains true."

Consider, for instance, water droplets moving along a glass surface and along a Teflon surface. Compared to the relatively sticky (i.e., hydrophilic) glass surface, water beads and moves more easily on non-stick (i.e., hydrophobic) surface, such as Teflon. Droplets, which move mostly by a rolling motion, are unaffected by surface slip, although they move more easily along a more hydrophobic surface.

The primary question, however, is the movement of liquid in continuous flows, where it must slip on a surface to flow more easily. To determine if surface wettability would make a difference to continuous flow in microchannels, Choi measured the slip length on a planar hydrophobic surface while at Brown University, and found it to be about 20-30 nanometers, or thousands of times smaller than the width of a human hair.

The nano-engineered material Kim and Choi have created at UCLA has a dense forest of sharply tipped nanoposts, which greatly limits contact between a liquid and the surface of the solid. The height of the posts, their shape, and the large number in a small space combine to create a thick layer of air beneath the liquid and to keep it from filling the gaps between the posts.

"We're using surface tension to keep the liquid out of the gaps, and in most practical flow conditions (e.g., pressurized flows) those gaps need to be very, very small," explained Kim. "So we've created a surface with a high density of sharp-tipped posts – submicron density – and then treated them to be hydrophobic."

At the suggestion of their colleague, UCLA mechanical and aerospace engineering professor Pirouz Kavehpour, Choi used a rheometer—a commercial tool used to measure viscosity—to track slip length along their surfaces. Although reliable and accurate, the rheometer lacks the precision to measure conventional miniscule slip lengths. But it may work for the very large slip Kim and Choi have on the nano-architectured surface.

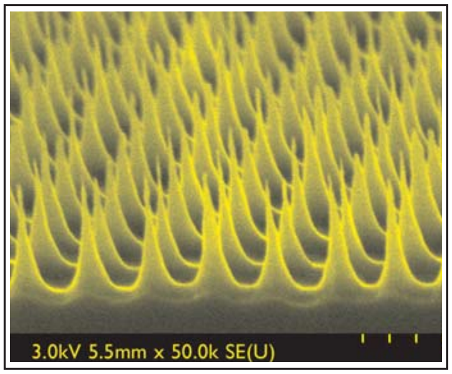
"The rheometer gave us repeatable results, very quickly," said Kim. "And it showed that the nano-engineered surface had a 20-30 micrometer slip length, a thousand times larger than on a conventional hydrophobic surface. We were expecting the results in this range based on our analysis and others', but were still surprised and very pleased to see it validated in testing."

When the UCLA Henry Samueli School of Engineering and Applied Science researchers published their results in *Physical Review Letters* earlier this year, they received considerable response from the physics community.

"Fluid dynamics is a classical field, and while our results do not change a long-held belief about the behavior of moving liquids where they touch solids, we have worked around the assumption by creating a surface with a minimal liquid-solid contact," noted Kim. "The slip length along the new surface is far more than what was previously assumed possible for flows under pressure. This degree of slip is now large enough to be useful for engineering applications and not just limited to the microscale."

In addition to developing a low-friction surface for use in fluidic applications such as underwater vehicles and tools for DNA analysis and real-time, on-site testing and monitoring for early detection of hazardous materials, UCLA researchers are exploring new uses for the innovative surface.

Kim and Choi also are working with bioengineering professors Ben Wu and James Dunn on the fabrication of new surfaces for cell growth.

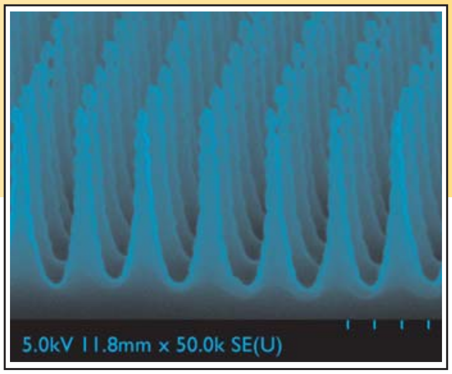


*Courtesy of Chang-Hwan Choi and CJ Kim.*

"We know cells grow well under certain conditions, but at the nanoscale most of the changes to date have been in the chemical conditions; little attention has been paid to the physical conditions," said Kim. "We're approaching it from a new direction and fabricating different surfaces. We're able to make the surface as elaborate as needed, which is basically a new capability at the nanoscale."

In addition to addressing basic scientific questions about the physical manipulation of cell growth at the nanoscale, Dunn and Wu hope to use the process for advances in medicine.

"There are many potential applications for this work," explained Dunn, "one is tissue engineering. If we're able to change the cells' orientation using the nano-textured surface, we can make the cells line up in a particular way to form the shape and structure of the tissues that we need."



*Courtesy of Chang-Hwan Choi and CJ Kim.*

Added Wu, "We are currently investigating the molecular basis of the cells' interactions on different nanostructures. If we are successful, we can use this knowledge to control the surfaces to regulate cell behavior. Our research in this area is really just the tip of the iceberg."

To create the well-regulated nano-engineered surfaces, Kim and Choi use interference lithography to etch the pattern on a silicon substrate, followed by deep reactive ion etching. To make sharp tips on the posts, they heat the silicon, creating silicon oxide, which is then removed.

The current method of manufacturing is practical for small area applications, but the UCLA researchers are exploring polymer as an alternative material to decrease costs for large volume area applications, as on the surface of a torpedo. They also are exploring applications for the silicon material in field emission displays and tips for atomic force microscopes.