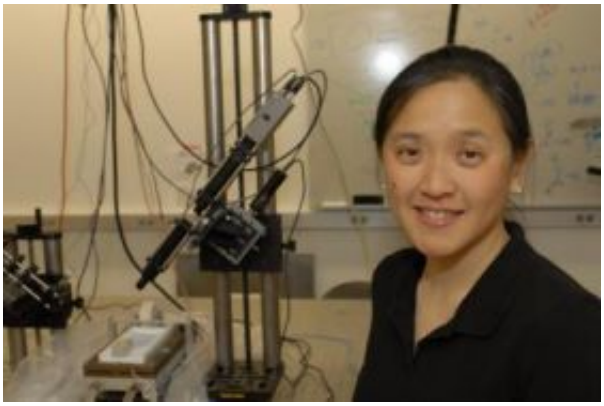
Research puts new wrinkle in study of materials folding under pressure

May 15 2008



Ka Yee Lee, associate professor in chemistry at the University of Chicago, and her associates study the characteristics of lung surfactant, a microscopically thin membrane that facilitates breathing. Photo by Beth Rooney

Scientists at the University of Chicago and the University of Santiago in Chile have explained, for the first time, the physics that governs how thin materials at scales millions of times different in thickness make the transition from wrinkles into folds under compression.

The study stems from a research program at the University of Chicago aimed at understanding the characteristics of lung surfactant, a microscopically thin membrane that facilitates breathing. But the findings would apply both to the design of foldable electronics and to the production of synthetic lung surfactant for therapeutic uses.

"Our paper is getting at the generality of these types of transitions," said Luka Pocivavsek, an M.D./Ph.D. student at the University of Chicago. Lung surfactant has the ability to wrinkle and fold under pressure, then gracefully pop back into a stiff configuration when relaxed. "It's not necessarily something special about lung surfactant that lets it do this. It's really the fact that lung surfactant behaves like an elastic, thin sheet," Pocivavsek said.

He and his co-authors will publish their results in the May 16 issue of the journal *Science*. His co-authors include Ka Yee Lee, Associate Professor in Chemistry, and Binhua Lin, Senior Research Associate in the Center for Advanced Radiation Sources (CARS), both at the University of Chicago; and Enrique Cerda, Associate Professor of Physics at the University of Santiago. Also contributing to the study were two summer researchers: SebastiÃ¡n Johnson, an undergraduate exchange student from the University of Santiago; Andrew Kern, a 2007 graduate of the University of Chicago Laboratory Schools, now at Northwestern University; and Robert Dellsey of Tulane University.

Lee's laboratory typically works with materials that resemble lung surfactant, which measures only 2 nanometers in thickness (the width of several atoms). "When we breathe, lung surfactant is compressed in the air sacs during exhalation," Pocivavsek said. "It's compressed so far that eventually it has to transition from being just a flat surface to something that's now crumpled."

The chief component of lung surfactant is called dipalmitoylphosphatidylcholine (DPPC). Pocivavsek likened DPPC in its purest form to a porcelain plate. "If you push on it hard enough, it's going to crack," he said. If lung surfactant consisted of 100 percent DPPC, the cracked pieces would hold together under the pressure during exhalation. But the plate would fall apart upon inhalation, which would decrease the stress.

Scientists can alter the properties of their experimental surfactants by mixing another type of lipid (fat) with the DPPC. The "magic lung-surfactant-lipid composition" is approximately 70 percent of the electrically neutral DPPC and 30 percent of a charged lipid, Lee said.

"It's a tricky thing," she said, balancing the stiffness of DPPC with the fluid behavior of the other lipid component. "In natural lung surfactant, various lung surfactant proteins are involved as well."

Lee and Pocivavsek have attempted to clarify what causes the wrinkle-to-fold transition in experimental lung surfactant under stress, but with inconclusive results. "It's just a difficult experiment because the lipid film is so thin and other competing effects prevent us from unequivocally observing the transition," Lee said.

But thanks to the Chicago-Chile Inter-American Materials Collaboration, funded by the National Science Foundation, Pocivavsek began a new line of related experiments on wrinkling and folding in a much thicker polyester film to get insights into the wrinkling-to-folding transition. At 10 microns thickness--narrower than a hair--the polyester film is thick enough to see with the naked eye.

Pocivavsek spent three months at the University of Santiago in 2006 with the theoretical collaborator of the project, Enrique Cerda, returning for another month last December. In Santiago, Luka started exploring the response of polyester films when put under stress. "They do some really amazing science," Pocivavsek said of Cerda and his associates.

Pocivavsek continued the experiment in Lee's laboratory upon his return from Santiago. Along with summer students SebastiÃ¡n Johnson and Andrew Kern, he was able to precisely measure the wrinkles and folds in the polyester film. Binhua Lin at CARS, meanwhile, used light microscopy and X-ray techniques to measure wrinkling and folding in

three layers of gold nanoparticles measuring only 15 nanometers in thickness. Working with Pocivavsek and Dellsy, her experiments provided data on a third type of material at yet another length scale. The collaboration was further enhanced by Cerda's visit to Chicago last summer.

These findings enabled the group to verify Cerda's theoretical calculations about how lung surfactant behaves, and document the universal dynamics of wrinkling and folding over a vast range of length scales in different materials.

When first compressed, an elastic material begins to wrinkle. The stress then focuses at a certain point, causing a trough or a peak to grow. Lung surfactant has the ability to reverse this stress focusing, allowing the folding that occurs on exhalation to smoothly stretch back into its previous state with inhalation.

A crumpled piece of paper shows ridges when flattened out again because there is nowhere for the focused energy to escape. Not so with a membrane stretched over a reservoir, where fluid will absorb the energy, preventing ridge formation. The principle has technological as well as biomedical implications.

"What if we want to have electronic paper?" Lee asked. "Make a polymer composite that would never wrinkle."

And in the biomedical arena, researchers may be able to develop a therapy for sufferers of Respiratory Distress Syndrome that mimics the physical properties, rather than the chemical composition of natural lung surfactant. "We might not necessarily have to use the particular lung surfactant components that nature uses," Pocivavsek said.

Source: University of Chicago