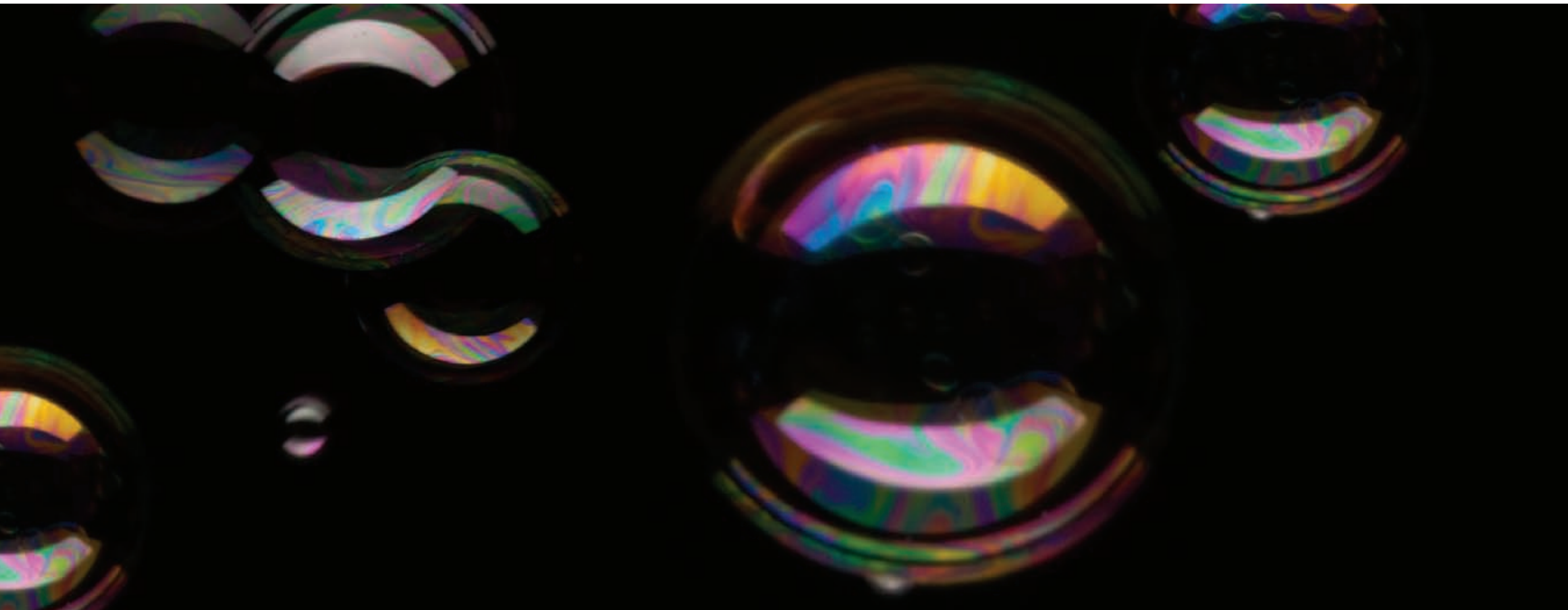


The Nano Guru

By Janelle Weaver

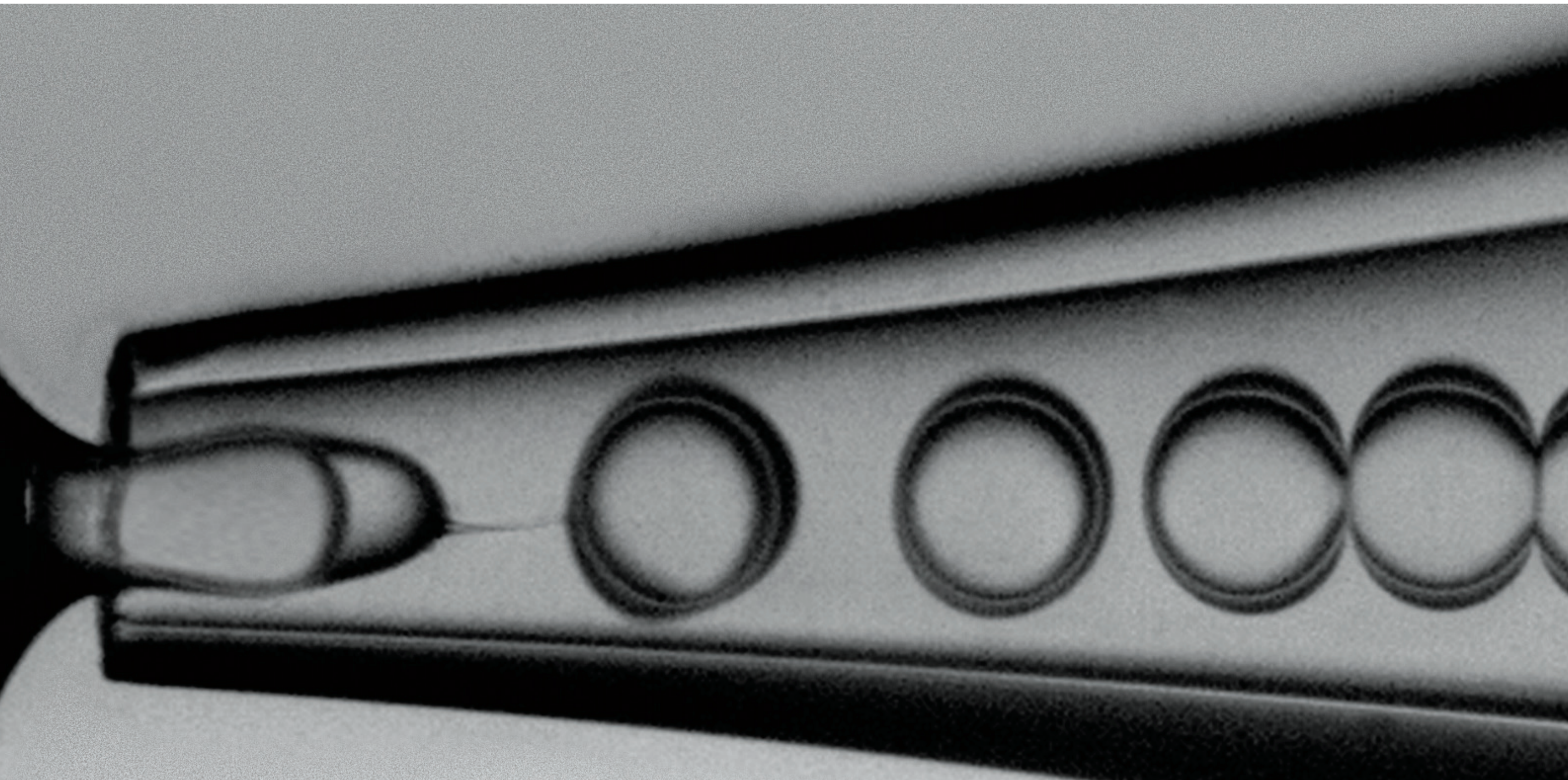
Films made of nanoparticles are a crucial component found in everything from lithium ion batteries and solar cells to the next generation of display devices and anti-fogging coatings for automobile windshields. One vexing problem facing engineers is that cracks routinely form in nanoparticle films during formation, interfering with their ability to work properly. Traditional techniques to prevent crack formation, such as adding substances to make the films stronger, can also compromise their function.

With the goal of developing stronger, tougher nanoparticle films, Daeyeon Lee, assistant professor of Chemical and Biomolecular Engineering, recently reported a new method to tackle this problem. By stacking multiple, thin nanoparticle layers while making films, he discovered that it's possible to prevent the formation of cracks. Lee is also exploring ways to enhance the damage tolerance of nanoparticle films using non-spherical nanoparticles. He envisions this approach being useful for the development of flexible solar cells and batteries as well as other electrical and optical devices that can resist cracking in response to mechanical stress.

Despite the technical nature of this research, Lee loves to give playful summaries of his own work, according to Ph.D. candidate Kwadwo Tettey, who joined the lab in the spring of 2009. "Recently, he gave a talk at a venue in Philadelphia entitled *Beers, Bubbles, and Beyond*," Tettey says. "It's interesting to see that he could break down his research to a very broad audience. He does this really well, and with a sense of humor." Lee's enthusiasm for science is contagious in the lab, Tettey adds. "He's a really engaging person and very passionate about research in general. This attitude rubs off on his students and keeps them motivated."

Tettey is also inspired by Lee's approach to scientific problem solving. "He likes to know why something

Daeyeon Lee



The Lee Research Group has developed a unique method to control the flow of multiphasic fluids to generate emulsions and bubbles. Shown above is the production of highly monodisperse double emulsions using a capillary microfluidic device.

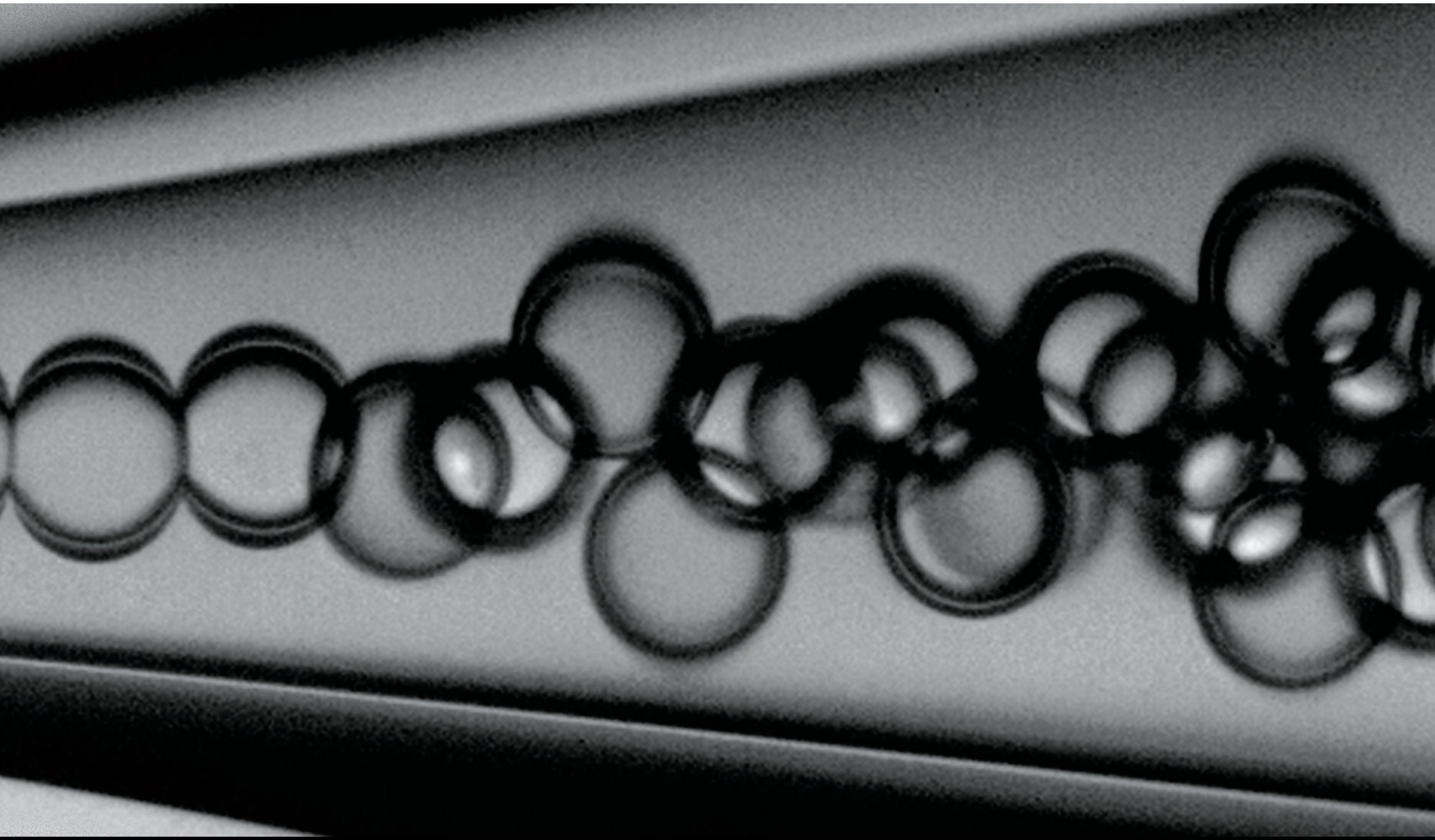
works, he doesn't want to just make something work," Tettey says. "That changed my perception of how I should approach science, and made me try to figure out the fundamental behavior of what I observe. As a scientist, that's a very important curiosity to have, because it gives you better control of the end product."

"God Particles" to the Rescue

To better control the end product in another research project, Lee has turned to a special type of particle named after the Roman god of beginnings, transitions and endings. Similar to its namesake, a Janus particle has "two faces," that is, two surfaces with distinct physical properties. For instance, one half of its surface may be hydrophilic, while the other half is hydrophobic. At fluid-fluid interfaces, such as those that form in mixtures containing oil and water, the water-loving region of a Janus particle spontaneously faces the water side of the interface, while the water-hating region orients itself toward the oil side.

Because of their unique two-faced property and strong attraction to fluid-fluid interfaces, Lee believes that Janus particles are ideal for producing thermodynamically stable mixtures consisting of different fluids that stay evenly dispersed rather than separating into distinct layers. By understanding and ultimately controlling the behavior of Janus particles at fluid-fluid interfaces, he hopes to optimize the properties of a range of soft materials, from vaccines and mixture-based medicines to detergents and microreactors for biofuel conversion.

To study Janus particles, Lee often first develops numerical models to predict their behavior at



fluid-fluid interfaces, and then observes their behavior under the microscope to confirm these predictions and generate new information to further develop the theories. "The biggest challenge is that we cannot see everything that's happening, so it's very difficult to come up with the exact mechanism to describe what's leading to the macroscopic properties or phenomena that we observe," Lee says. "That's why we need to have this crosstalk between modeling and experiments."

Lee has discovered that by tweaking the shape of Janus particles, morphing them from spheres to snowman-like particles, and then modifying the relative size of the snowman's hydrophilic head compared with its hydrophobic body, he can control their orientation, behavior and interactions at fluid-fluid interfaces. Lee's calculations for guiding the synthesis of non-spherical Janus particles can be used to stabilize fluid mixtures, thereby extending the shelf life of food, medicine and personal hygiene products, and also enabling enhanced oil recovery from oil fields.

Synergistic Impact

Lee grew up in South Korea and earned his bachelor's degree in chemical engineering at Seoul National University in 2001. Encouraged by his undergraduate advisor to become a scientist, Lee decided to come to the United States for the best opportunities to pursue his dream. While earning his doctoral degree in chemical engineering at the Massachusetts Institute of Technology, he initially focused on polymers and then started to apply techniques in polymer science to soft nanomaterials.

These diverse research experiences prepared Lee for joining the Penn faculty in 2009. "If I were at another place, it would be difficult to imagine how my research could impact people in other fields, but collaboration is so natural at Penn. I now have several projects with the medical school," he says, pointing out its close physical proximity with Penn Engineering.

One of his collaborators is Rebecca Wells, associate professor of Medicine, who is interested in the role of proteoglycans, collagen and tissue stiffness in liver fibrosis. After hearing Lee give a presentation at a Center for Engineering Cells and Regeneration luncheon a few years ago, she approached him to discuss a potential collaboration. Since then, Lee has worked with Wells to develop a new kind of cell culture system that consists of a collagen matrix whose stiffness and proteoglycan content can be tuned, mimicking the cellular environment of the liver. "These kinds of culture systems are going to enable us to understand cell behavior in a much more realistic way," Wells says.

Lee's innovative work has not gone unrecognized. In 2011, he received the coveted National Science Foundation CAREER Award to study electrostatic interactions in non-polar solvents for the assembly of nanostructured thin films for alternative energy applications. "I work on the fundamental side, but I always have in mind how my research could influence new applications. I think the areas where my research will have the greatest impact are energy storage and conversion, biomedicine and water purification," Lee says. "The value of being a scientist is that you get to do something that you love to do, and you can also have a positive impact."