Basu. "We can also easily adapt this process to coating long tubes."

Simulations Reveal Morphological Transition in Simple Foams

By deriving an equation of state for compressible foam and then simulating it numerically, researchers at the University of Illinois predict a dramatic morphological change that will occur as the surface tension is increased or, equivalently, the volume of the foam is greatly expanded. Foams are ubiquitous in nature and widely used in industry, from foamy foods such as bread and ice cream to foamy materials such as plant stems, bones, magma, and foam rubber. All foams have one characteristic in common: The bubble-delimiting films minimize surface energy by encapsulating the largest volume while using the least amount of material.

Hassan Aref, professor and head of the Theoretical and Applied Mechanics Department, said, "In a common liquid foam, like a soap froth, the elastic energy in the films is negligible compared with the work required to compress the air in the bubbles. The individual bubbles, which are often of roughly comparable size, retain constant volumes, except for the slow redistribution of gas by diffusion or the rupturing of films between bubbles. If you imagine greatly enhancing the surface tension, however, the elastic energy in the films will compress most of the bubbles, leading to a very different structure."

To investigate this phenomenon, Aref and graduate student Dmitri Vainchtein first derived the equation of state for compressible foam. "This equation shows that foam with a free boundary will expand to a maximum volume if the external pressure is lowered at constant temperature," Aref said. "The equation also suggests that the same foam—when enclosed in a container—can be expanded further but will become unstable at a certain volume that we can predict."

Though difficult to explore experimentally, as reported in the December 1999 issue of *Physics of Fluids*, the nature of the instability was revealed in a series of numerical simulations. Aref said, "We observed what may be described as two 'phases' of foam. In one phase, we have a large number of small bubbles clustered together. In the other phase, we must then have a small number of much larger bubbles that occupy most of the space in the container."

The increased surface tension appears to compress most of the bubbles, forcing the remaining bubbles to expand to fill the space, Aref said. This phenomenon might provide a model for the undesirable formation of large voids in solidifying foams, including those that form when baking bread. "As bread is baked, the bubble membranes begin to harden, which may roughly correspond to an increase in surface tension," Aref said. "The resulting segregation instability results in a loaf that contains clusters of tiny bubbles embedded in a background of a few much larger bubbles."

Carbon Nanotubes Exhibit Tensile Strength of 63 GPa

Researchers at Washington University in St. Louis have found that 63 GPa is the highest tensile-strength value of the outermost shell of a single nanotube. In an experiment performed by Rodney S. Ruoff, associate professor of physics, and his research group, individual multiwalled carbon nanotubes (MWCNT)—rolled sheets of graphite—were picked up, positioned, and firmly attached on a nanometer length scale, and tested with tension until broken.

As reported in the January 28 issue of *Science*, MWCNTs break with what Ruoff refers to as a "sword-in-sheath" mechanism. "These are 'Russian matryoshka doll-like' structures," Ruoff said. "One nanotube is nested inside of another, which is inside of another, and so on. For the MWCNTs we mechanically loaded, there would be typically 10 to 40 nested cylinders."

"Our method of 'nano-welding' these onto the cantilever tips, which are our 'fingers' for holding and pulling, is to focus the electron beam onto the MWCNT, where it is loosely attached by the relatively weak van der Waals forces to the cantilever tips," said Ruoff. "Doing this causes residual hydrocarbon gases in the electron microscope to be decomposed and to build up a small carbonaceous deposit. This deposit is the strong attachment that holds the nanotubes in place during the experiment."

The method needs further development, he said. About one-half of the MWCNTs attached in this manner still broke at the attachment site rather than within the loaded nanotube section after the load was applied. But the other half represented 19 separate MWCNT tensile-loading experiments.

Ruoff said, "Since the attachment is to the outermost shell, and the interaction between these nested nanotubes in a multiwalled nanotube is relatively weak, one might expect that the outermost shell will carry the load and break, with pullout of the inner shells then occurring immediately after the break. This is exactly what we observed."

"When we take account of the lower density of carbon nanotubes as compared to high-grade steels, the outer shell is about 50 to 60 times stronger. This suggests that there are future applications for very lightweight, high-strength cables and composites, where the carbon nanotubes are the load-carrying element," Ruoff said.

V_2O_5 Nanofibers Used in Fabricating Field-Effect Transistor

G.T. Kim, J.G. Park, and Y.W. Park of Seoul National University, and J. Muster, V. Krstic, S. Roth, and M. Burghard of the Max-Planck Institute in Stuttgart have demonstrated that vanadium pentoxide (V_2O_5) nanofibers can be readily deposited in controllable densities on chemically modified Si/SiO_2 substrates. The feasibility of using these nanofibers for electrical conduction in nanoscale devices is being investigated. Current attempts to use carbon nanotubes for this purpose suffer from the tendency of the nanotubes to form in dense networks, requiring potentially damaging ultrasonic treatment to separate the individual fibers. The deposition of V_2O_5 nanofibers requires no such separation step.

As reported in the April 3 issue of *Applied Physics Letters*, nanofibers of V_2O_5 of molecular thickness are synthesized from ammonium(meta)vanadate and an acidic ion exchanger. To fabricate a field-effect transistor (FET), the nanofibers are deposited on a Si/SiO_2 substrate, and 15-nm-thick Au/Pd electrodes are patterned on the surface 100 nm apart using electron-beam lithography. A 300-nm-thick layer of thermally grown SiO_2 insulates the electrodes from a back gate consisting of the substrate doped with As^+ ions. The measured resistance of the V_2O_5 fibers connecting the electrodes ranged between 200 MΩ and 300 MΩ. This relatively high resistance limits the performance of the FET in its present version; further investigation using fibers with higher conductivity (such as VO_2 or V_2O_3) is planned.

Ultrafast Laser Pulses Facilitate Storage and Retrieval of Quantum Phase Information in Cesium Rydberg States

Using ultrafast lasers and a beam of cesium atoms, physicists at the University of Michigan have created a database that stores and retrieves data in atomic quantum phases. As reported in the January 21 issue of *Science*, a computer randomly assigned data values to one quantum state of a single cesium atom. Using an ultrashort pulse of intense laser light, the scientists stored the information in the assigned quantum state by flipping the quantum phase or inverting the quantum wave for that state. Less than 1 ns later, the same atom was hit by a second laser pulse, which located the stored data by amplifying the flipped quantum state and suppressing all other states in the wave packet. The laser pulse used to store the data was produced by filtering a 100-fs laser pulse centered approximately on λ = 785 nm. The cesium atomic states interrogated were Rydberg *p*-states, with principal quantum numbers ranging from $n = 29$ to $n = 38$.

Philip H. Bucksbaum, the Otto Laporte Professor of Physics at Michigan, said that L.K. Grover, in a 1997 paper published in *Physics Review Letters*, speculated that quantum 2-state data registers would be a faster, more efficient way to search and retrieve data than the classical binary system currently used because the rules of quantum mechanics allow a search in many locations simultaneously. "We test-