part of the refractive index to the imaginary part, optimal around 1410 nm, is an order of magnitude higher than any previously reported material, bringing this system closer to practical optical applications. If this device can be further optimized, they said, it may allow for extremely counterintuitive applications at telecom wavelengths, including the creation of a "perfect" lens whose resolution is not limited by the optical wavelength.

COLIN MCCORMICK

Surface Interactions Can Significantly Alter Fluid Properties at the Nanoscale

Confining fluids in nanometer-scale channels can affect how the molecules pack together, how they withstand compression, and their ability to rapidly mix or flow. Changes to the first two properties are relatively well understood, but predicting the third, which is connected to the mobility of the molecules, has proven elusive until now. T. Truskett of the University of Texas at Austin and J. Errington of the State University of New York at Buffalo, with graduate student J. Mittal of UT–Austin, have discovered that the key to predicting changes to mobility in a confined fluid resides in the relationship between mobility and excess entropy.

"One of the most dramatic changes you see going from macroscopic scales to nanometer scales is that materials can actually change their state," Truskett said. "A solid may become liquid upon confinement. If that solid material is a bonding agent and it turns into a runny fluid, it doesn't do its job. Likewise, a liquid can become a solid when confined to small scales. If it is a lubricant, it fails. So in the engineering of nanoscale devices, these kinds of changes can have potentially catastrophic effects."

In a bulk liquid, such as a glass of water, fluid molecules

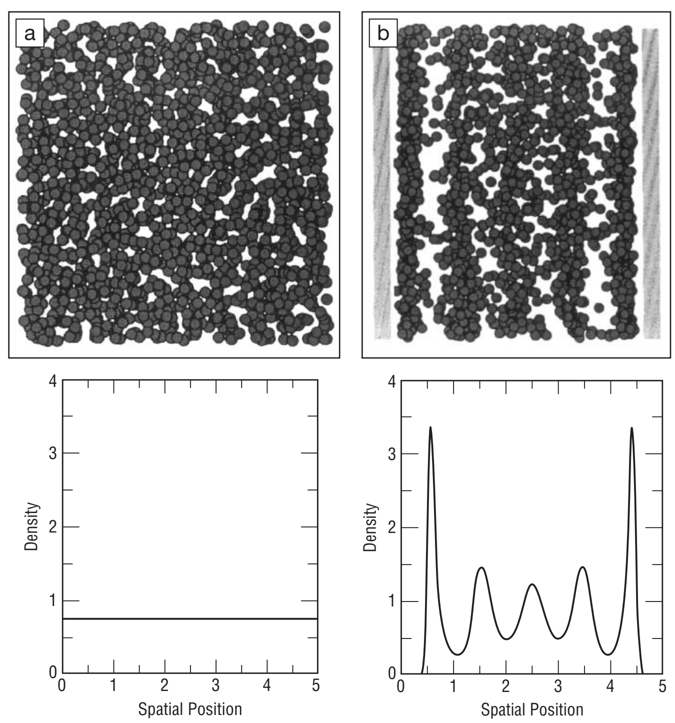

Figure 1. Graphic showing a comparison between the packing arrangements and spatial-density profiles of a simulated hard-sphere fluid in (a) bulk and (b) confined environments. Although the two materials show very different average structures, they exhibit the same excess entropy (a measure of randomness) and diffusivity (a measure of mobility). Courtesy of Thomas Truskett.

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interact primarily with other fluid molecules. Relatively few are in contact with the surface of the container. At nanometer scales, however, a much higher proportion of molecules come in contact with the confining material. This surface interaction can significantly alter fluid properties, including molecular mobility, according to the research team.

As reported in the May 5 issue of *Physical Review Letters* (#177804; DOI: 10.1103/PhysRevLett.96.177804), the group performed molecular dynamics simulations to study the behavior of hard-sphere fluids in highly restrictive channels with different shapes and boundary interactions. They modeled changes to fluid mobility and entropy in these conditions, a critical breakthrough that will allow engineers to learn how these changes occur while avoiding the difficult task of gathering experimental data on such small scales (see Figure 1).

"One way to think about how mobility relates to entropy is to think of entropy as measuring a sort of randomness at the molecular level," Truskett said. "In a gas, where the molecules are randomly distributed, entropy is high and the gas mixes readily. In a solid, the molecules are aligned in a regular spatial pattern; there is little randomness and the solid barely mixes at all. Our discovery is that while both excess entropy and mobility of a fluid are affected by confinement, the relationship between the two quantities essentially remains the same down to very small scales."

Because scientists already have reliable methods for predicting how confinement will affect excess entropy, they can now use this information together with the group's findings to predict how confinement will affect fluid mobility.

Buried Interfaces Imaged Using Noncontact Picosecond Acoustic Microscopy

Early identification of failures in semiconductor and nanoelectronic devices, such as delaminations and voids, is crucial so that defective parts can be screened out. Nondestructive characterization and identification of such failures is a major challenge. Scanning acoustic microscopy with a single spherical lens is typically used for inspecting such failures. The technique involves the generation of ultrasound by a piezoelectric transducer focused with a spherical lens, with both the lens and sample immersed in a coupling medium, usually water. One of the limitations of this technique is the attenuation of the ultrasound at high frequencies. In addition, immersion in the coupling medium renders samples unsuitable for additional processing. To overcome these shortcomings, a new noncontact, nondestructive technique that involves generating and detecting ultrahigh-frequency acoustic waves directly on the sample has now been reported. S. Ramanathan (formerly at Intel Corp. and now at Harvard University) and D. Cahill of the University of Illinois at Urbana-Champaign describe this technique in the May 2006 issue of the *Journal of Materials Research* (p. 1204; DOI: 10.1557/JMR.2006.0141).

The technique involves coating the sample with an 80-nm-thick aluminum film that acts as a transducer to generate and detect acoustic pulses. In this case, the sample consisted of a silicon wafer covered by an oxide layer, an etch-stop layer, and a second oxide layer in which an array of copper metal lines was fabricated. The copper lines were each 6 μm wide, 40 μm long, and 1 μm thick. The lines on one of these wafers were bonded to the lines on a second wafer, which was used as a handle wafer. The topmost silicon layer was then thinned to 6 μm, and an aluminum transducer film was deposited. A Ti:sapphire laser beam was directed onto the aluminum surface, where the laser pulse generated a local stress field, leading to a short-duration longitudinal acoustic pulse that travels from the aluminum film into the Si substrate. A fraction of the pulse is reflected back toward the surface when it encounters a discontinuity in acoustic impedence, such as at an interface. The reflectivity of the metal film is changed slightly due to these echoes, which are measured by a time-delayed probe beam from the laser. The researchers observed echoes from the silicon/oxide interface, the oxide/etch-stop interface, the oxide/Cu interface, and the oxide/air interface. The researchers imaged buried regions of the sample by raster-scanning the sample beneath the pulse and probe beams at a fixed time delay. The strength of the changes in reflectivity at each sample point was collected, and the data were analyzed as an image. Figure 1 shows an example of an acoustic image of the copper lines taken at a time delay of 1.711 ns, corresponding to the acoustic return from the oxide/Cu interface. This is a gray-scale representation of the ratio of the in-phase and out-of-phase signals measured by an rf lock-in amplifier. The image shows a 200 μm × 200 μm area. No image processing, such as filtration or noise reduction, was applied. The researchers also imaged an isolated oxide/etch-stop interface, which, according to the research team, would be impossible with the conventional technique.

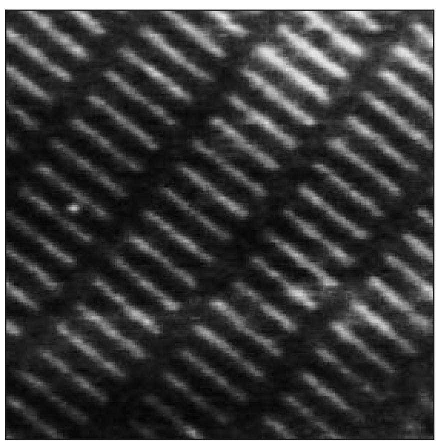

Figure 1. Acoustic microscopy image of copper lines imaged at a pump-probe delay time of 1.711 ns to select the acoustic echo from the oxide/Cu interface. The gray scale corresponds to variations in the change in optical reflectivity of approximately 15%. The 6 μm × 40 μm copper lines are clearly imaged through the 6-μm-thick silicon substrate. The image shows a 200 μm × 200 μm area. Reproduced with permission from the Journal of Materials Research ***21*** *(5) (2006) p. 1204; DOI: 10.1557/JMR.2006.0141. © 2006 by the Materials Research Society.*

The results of the study demonstrate the feasibility of the method as well as its potential use as an extremely sensitive probe of the mechanical reliability of interfaces. The technique has spatial resolution on the order of few micrometers, which is limited by the laser spot size, and nanoscale depth resolution. The technique can thus potentially be used for high-resolution analysis to identify failures. The researchers said that it may be possible to use a longer wavelength laser beam that is transparent to the silicon substrate, which could allow for acoustic pulse generation targeted directly at the interconnect layers, thereby overcoming the need for any external couplant.

GOPAL RAO

Gold Nanorods Optically Trapped

Optical trapping uses forces exerted by a strongly focused laser beam to trap small objects at the center of the beam. By exploiting the plasmonic property of gold nanorods, M. Pelton and co-workers at the University of Chicago have demonstrated that the rods can be optically trapped and oriented in three dimensions for more than 15 min. Resonances are known to enhance optical forces on particles, and the researchers use the fact that the optical gradient force on the gold nanorod is greatly enhanced when the