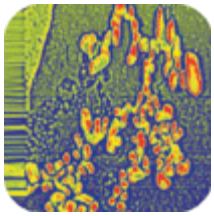
This week in Science

Sounding Out Subsurface Nanofeatures



Nondestructive subsurface imaging in the size range from 10 to 100 nanometers is particularly challenging but would be valuable in applications ranging from device construction to cell biology. **Shekhawat and Dravid** (p. 89; see the Perspective by Diebold) have developed a technique, scanning near-field ultrasound holography, that takes advantage of both the phase and amplitude of scattered ultrasound waves to produce nanoscale-resolution images of internal substructure. Examples include images of voids in polymer coatings of SiN shallow trench structures and malaria parasites in red blood cells.

CREDITS: SHEKHAWAT AND DRAVID

==========

***Science*, Vol 310, Issue 5745, 61-62 , 7 October 2005**
[DOI: 10.1126/science.1119259]

Perspectives

APPLIED PHYSICS:

Subsurface Imaging with Scanning Ultrasound Holography

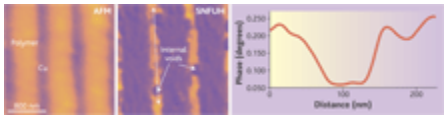
Alain C. Diebold*

Characterization of subsurface structure is critical to almost every area of science and engineering (1). In biology, for example, imaging the structure of cells has always been a fundamental means of understanding the relationship between structure and function. Moreover, every innovative microscopy technique seems to highlight new or difficult-to-observe features in biological systems. But some problems, such as finding life-threatening arterial blockages, require much better spatial resolution (1).

Some key microscopic imaging methods rely on sound waves rather than light. Perhaps the most prevalent application of acoustic microscopes is for imaging subsurface features

in packaged electronic parts. Subsurface voids can be the root cause of coating delamination or can result in the fracture of a critical structure under stress. As Shekhawat and Dravid report on page 89 of this issue, a novel form of acoustic holography has now extended the spatial resolution of this technique, thus enabling the imaging of subsurface features in a wide range of applications (2).

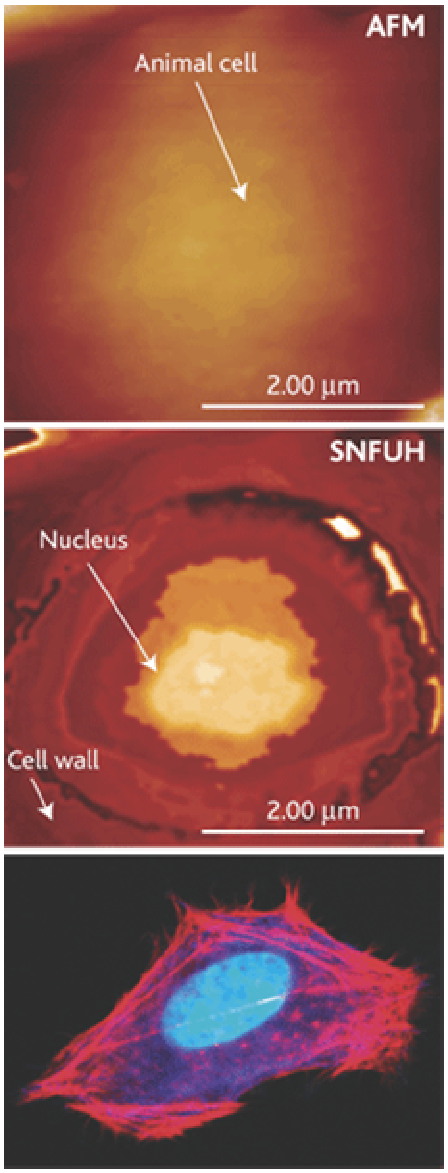
A conventional scanning acoustic microscope focuses acoustic waves under the surface of a sample by means of a transducer (often made from sapphire) and scans the sample under the transducer. The sample is immersed in water. The spatial resolution is given by an equation similar to the Rayleigh criterion for a light microscope, namely $\omega = 0.51\lambda_0/NA$, where $\lambda_0 = v_0/f$, v_0 is the velocity of sound in the fluid, f is the frequency of the acoustic wave, and NA is the numerical aperture. For typical acoustic microscopes, the spatial resolution is close to 100 μm. Recently, scanning probe microscopy has extended the spatial resolution to the nanometer scale (3).



Fine lines. SNFUH imaging of a copper low-dielectric interconnect system. (**Left**) Typical AFM (topography) image shows periodic polymer and copper features. The copper lines are about 60 nm wide and the polymer one around 200 nm. (**Middle**) Phase image of SNFUH that clearly reveals the surface elastic contrast and subsurface voiding in the copper lines. (**Right**) Line profile across the voids.

CREDIT: G. S. SHEKHAWAT, V. P. DRAVID/NORTHWESTERN UNIVERSITY

To obtain images of integrated circuit technology, however, much greater spatial resolution will be required. The width of metal lines is quickly approaching 60 nm, and by the year 2008 memory chips will have so-called dense metal lines 60 nm wide with spaces of 60 nm between them. Previous efforts had already pushed acoustic imaging resolution well below the limits of the scanning acoustic microscope. Geer *et al.* have demonstrated that the ultrasonic force microscope can image changes in the elastic modulus with a resolution of <10 nm (3). This group ultrasonically vibrated the sample at 2.2 MHz while scanning the surface with an atomic force microscope (AFM). The apparatus is similar to that previously reported by Dinelli *et al.* (4). The spatial resolution was good enough to observe differences in the low dielectric constant film caused by variations in the processing (3).



Better bioimages. (**Top**) Image of mouse cell taken with conventional AFM technology. (**Middle**) SNFUH image of the same cell. (**Bottom**) Micrograph of mouse fibroblast cell for comparison (nucleus is blue, actin protein in cell's skeleton is shown in red).

CREDIT: (BOTTOM PANEL) DAVID BECKER/PHOTO RESEARCHERS, INC.

Now, Shekhawat and Dravid have shown how scanning near-field ultrasound holography (SNFUH) can further improve spatial resolution and depth information (2). In SNFUH, acoustic waves are launched on both the probe tip and the sample at slightly different megahertz frequencies. The interference of these two waves forms a surface acoustic standing wave. This wave is altered by subsurface features such as voids, and the change in its frequency is monitored by the AFM cantilever. Shekhawat and Dravid operate the AFM in the contact mode for hard materials and the noncontact mode for biological materials. The next step for this approach will be to develop the modeling to determine the depth dependence of the response from buried features turning two-dimensional maps into three-dimensional tomography maps.

Shekhawat and Dravid have also applied their technology to copper damascene structures

observation of a void in an opaque material had previously seemed to be a ***nearly impossible*** task.

But semiconductor structures are not the only application of near-field acoustic microscopy. Shekhawat and Dravid have illustrated the imaging capability of SNFUH for biological samples. In the top panel of the second figure, a typical AFM (topography) image shows a mouse cell on a cover slip, which was treated with phosphate buffer solution. It only shows the overall outer morphology of the cell. In the middle panel of the second figure, however, the SNFUH image appears to reveal the internal substructure of the cell, including the nucleus. It is instructive to compare the SNFUH image with a typical micrograph of an animal cell (the bottom panel of the second figure). Extra structure is observed with this additional resolution.

With further research and development, SNFUH should be able to provide even more information, such as the depth of buried features and further quantification of elastic properties.

References

1. J. Ouellette, *Indus. Phys.* **10** (1), 14 (2004). [Full text]
2. G. S. Shekhawat, V. P. Dravid, *Science* **310**, 89 (2005).
3. R. E. Geer,O. V. Kolosov, G. A. D. Briggs, G. S. Shekhawat, *J. Appl. Phys.* **91**, 4549 (2002). [AIP]
4. F. Dinelli, S. K. Biswas, G. A. D. Briggs, O. V. Kolosov, *Phys. Rev. B* **61**, 13995 (2000). [APS]

The author is a Fellow with SEMATECH, Austin, TX 78741, USA. E-mail: alain.diebold@sematech.org