

Infrared tissue scans


Ultrasound and x-ray imaging give physicians a view of macroscopic structures in the human body, down to millimeter resolution in some cases. But to look at structures on the microscopic level normally requires light. Because light does not penetrate tissue, this requires taking biopsies and sending them to the lab.

fers from several limitations besides short penetration. The data is built up by a point-by-point scan, similar to a computerized tomography (CT) X-ray scan, and then transformed into an image by a computer. During this brief scan, motion can blur the image. In addition, the image contains absorption data but not phase data, as

process selects out the photons that have been scattered only once, and thus retain their coherence.

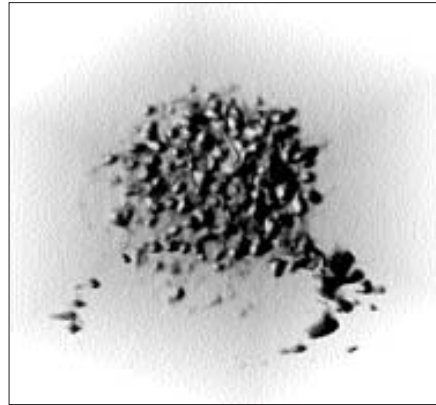
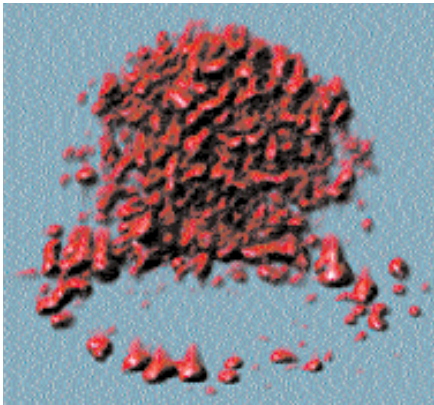
The hologram is recorded on an electronic medium made up of photorefractive quantum wells, a decade-old technology. The recording device consists of 100 layers of gallium arsenide and aluminum gallium arsenide quantum wells, whose refractive index changes in response to light and IR radiation. The hologram is built up by combining 1,000 laser pulses and is refreshed every 10 μ s. This fast reaction time makes the system immune to motion-based blurring.

In the final step, the reference beam is used to read out the hologram and project an image onto a charge-coupled-device camera. Because it shows only a thin slice of tissue, the image can be rapidly scanned from top to bottom just by changing the delay on the reference beam. This gives the physician viewing the image a far greater sense of three-dimensional structure than a biopsy, in which individual slices must be compared slide by slide. The technique has been demonstrated on a rat tumor in vitro and may prove useful as a supplement to conventional microscopy.

“We are working to perfect the basic technology before going to in vivo testing on animals,” explains D. D. Nolte of Purdue’s department of physics, a team member. One phenomenon the group is investigating is a shimmering of the image—caused by microscopic movements within living cells—which is visible even at low magnifications. “Dead cells don’t have this shimmer, so we are hoping to develop a method that will help surgeons distinguish between dead and living cells when deciding whether to excise more tissue during surgery,” says Nolte. 

Better electronic paper

For convenience and readability, no electronic display technology has matched paper, belying predictions of a paperless office. But researchers have accepted the challenge of creating a display that is as thin and flexible as paper and has paper’s high reflectivity and contrast. One



Three-dimensional rendering of the volumetric holographic features observed in a 640- μ m-diam rat tumor is obtained from a hologram generated by a 120-fs near-infrared laser pulse and projected onto a charge-coupled camera.

In recent years, researchers have looked at ways to penetrate at least a short distance into tissue with infrared (IR) radiation, as a way to avoid biopsies or to use when biopsies are impossible. These techniques rely on the fact that IR radiation is not strongly absorbed by tissue even though tissue strongly scatters it. If a very short pulse of laser light shines through tissue, a small fraction of the photons will only be scattered once and will retain imaging information. Because these photons travel a shorter distance than those suffering multiple scatters, they arrive first and can be isolated by time-gating.

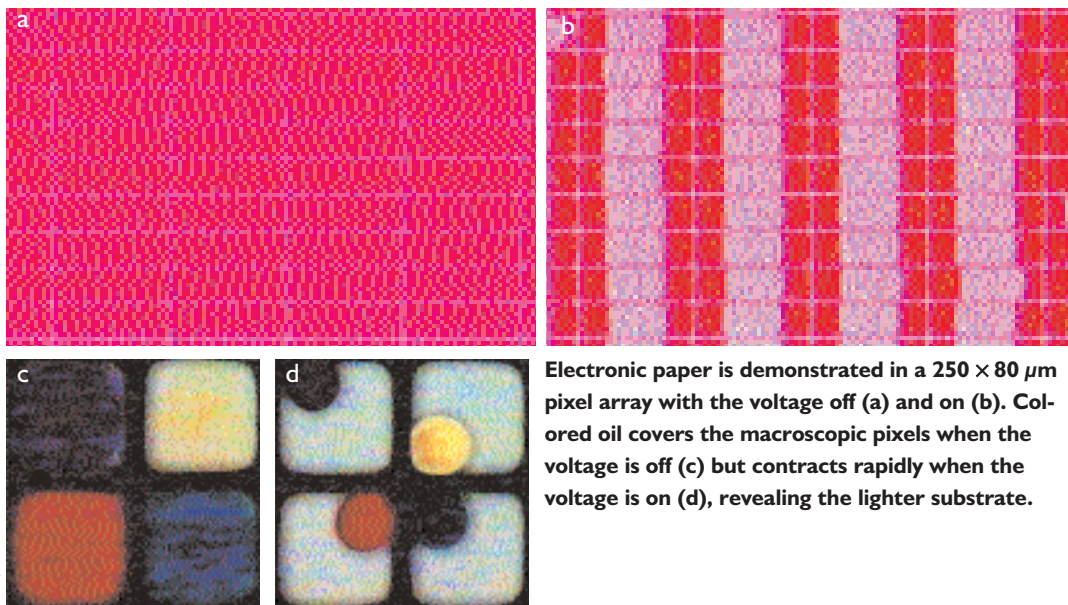
These imaging processes are limited to penetrating about 1 mm of tissue before the once-scattered photons become too rare to observe. Although this may not sound like much, it can be useful for examining the retina, where biopsies are impractical; for use with endoscopes within the body; and for scanning ahead during surgery to avoid, for example, severing critical nerves.

However, the existing technique, called optical coherence tomography (OCT), suf-

does an optical image of a biopsy slice, which makes interpretation more difficult.

To overcome these limitations, a research collaboration between physicists at Purdue University (West Lafayette, IN) and the Imperial College of Science (London, England) has developed a new technique, termed holographic optical coherent imaging or OCI (*Appl. Phys. Lett.* 2003, 83, 575). The process generates a real-time hologram that contains the full phase information from an image, just as an image obtained using a microscope would.

The process begins with a 120-fs pulse from a Ti:sapphire laser emitting 840-nm near-IR radiation. The pulse is split into a reference beam and an imaging beam. The imaging beam is reflected from the tissue’s upper millimeter, while the reference beam goes through an adjustable delay stage. The two pulses recombine at the holographic plate. The imaging pulse is spread out in time over a few picoseconds, having been reflected from various depths in the sample. However, only the part of the beam that arrives at the same time as the reference beam can form the hologram. The




Electronic paper is demonstrated in a $250 \times 80 \mu\text{m}$ pixel array with the voltage off (a) and on (b). Colored oil covers the macroscopic pixels when the voltage is off (c) but contracts rapidly when the voltage is on (d), revealing the lighter substrate.

commercialized technique involves moving colored particles in a liquid, but it is limited by a slow response speed.

Another approach uses electrowetting, which involves changing the wetting behavior of fluids in response to imposed electric fields. Robert A. Hayes and B. J. Feenstra at Philips Research (Eindhoven, The Netherlands) have demonstrated that such an electrowetting system can be made as thin as paper and have sufficient speed to display video images (*Nature* 2003, 425, 383). In their system, a pixel consists of several layers over a white reflective substrate—a transparent electrode, a thin hydrophobic insulator, and a layer of colored oil and water—all sandwiched below a plastic cap.

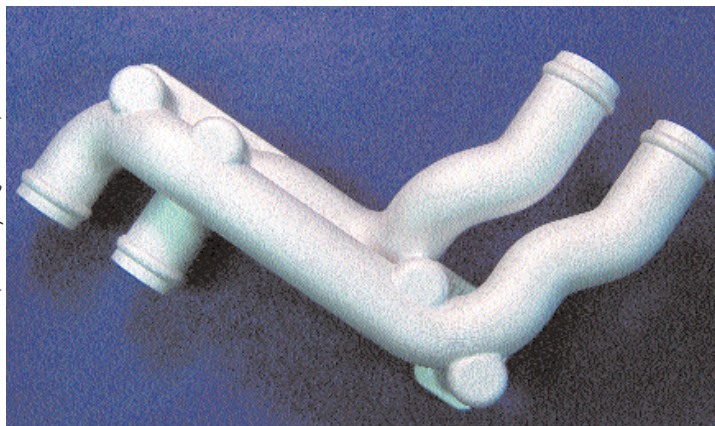
With no voltage applied, the oil layer spreads across the whole of the pixel, making it dark. But when a voltage is turned on, the insulator is no longer hydrophobic and the water pushes the oil into a small spot, making the pixel much brighter. Only low voltages of up to 20 V are needed, making thin driving layers possible. Response time is about 10 ms, fast enough for video, and because more than 80% of the white substrate can be exposed, a contrast level ratio of 15 is achieved, which is comparable to that of paper.

Potentially, the technique could improve the performance of color displays as well. In most such displays, one-third of a pixel is devoted to each primary color. But with electrowetting, a single subpixel can contain two separate oil layers and thus two colors. This doubles the brightness of a color display.

“Right now, we are working to expand the device from our 1,000-pixel prototype to a 30,000-pixel display by the end of the year,” says Hayes. Other issues that must be addressed before commercialization include making an adequately thin and flexible driving substrate and reducing costs. 

Rapid manufacturing

Producing prototypes or finished manufactured parts directly from computer inputs (rapid prototyping or rapid manufacturing) has become an increasingly important technique for fabricating precision parts. Rather than making molds or dies—a process that often takes weeks or months—rapid prototyping fabricates parts by creating point-by-point patterns in layers of powder, solidifying them with heat, and building up layer upon layer into an object.



A computer-guided laser polymerizes a pattern in a powdered mixture of aluminum, magnesium, and nylon to form a skeleton of 50% metal that is infiltrated with liquid aluminum to form the rapid prototype part.

Division of Materials, University of Queensland, Australia

Materials such as polymers, ceramics, steel, and aluminum are used.

For aluminum, a polymer–aluminum powder is fabricated using a rapid prototyping technique. Then the polymer is burned out and the remaining metal lightly melted or sintered together to form a solid part. However, as the metal skeleton melts together, its shape changes slightly, making it impossible

to maintain high precision and to form complex parts.

In recent years, however, a new liquid infiltration method has allowed high-precision rapid prototyping of metal parts. Most recently, T. B. Sercombe and G. B. Schaffer of the division of materials at the University of Queensland (Australia) have adapted this technique to aluminum (*Science* 2003, 301, 1225). In infiltration, a molten metal lightly coats a sintered skeleton and then solidifies to form the final part.

The rapid-prototyping process starts with a powdered mixture of aluminum, magnesium, and nylon. A computer-guided laser polymerizes a pattern in a layer of the powder, and another layer is laid down until the part is completed. At this point, the part is about 50% metal by volume.


The challenge to forming aluminum parts

by infiltration is that aluminum in air rapidly acquires an oxide layer that prevents the individual metal particles from binding together. To prevent this oxide layer, the Queensland team heated the part at 540 °C in a flowing nitrogen atmosphere, using the magnesium in the powder to scavenge

oxygen. This process resulted in an aluminum nitride layer that allowed the aluminum particles to join together into a skeleton so that the part could then be infiltrated without distortion.

After its initial heating, the part was heated at 570 °C for another 6 h, during which the liquid metal infiltrated it. For this procedure to work, the liquid melt must have a melting temperature above that at which the skeleton forms but below the skeleton's melting point. An alloy of aluminum, silicon, and magnesium has the right properties.

This process can yield complex parts with delicate features as small as 500 μm across and, theoretically, parts of any size. Tensile strength and ductility of the parts are about 80% of those of an aluminum casting, according to Schaffer. "The process is now very close to commercialization," he says.

While the process is much faster than conventional prototyping, it is not yet a mass production system. Schaffer estimates that around one part per hour would be the maximum production rate. 

Flipping storage fields

Storing data as magnetized specks of matter has allowed memory densities to increase steadily as the specks have gotten smaller. However, at nanometer scales, thermal fluctuations can randomly erase magnetic fields, and thus, the fields have to be made stronger. The problem is that one must reverse the field to write a new bit, and to do so, the magnetic writing field must be made equally strong. This could pose an ultimate limit on magnetic memory density because the magnetic-field strength needed might eventually become impractically high.

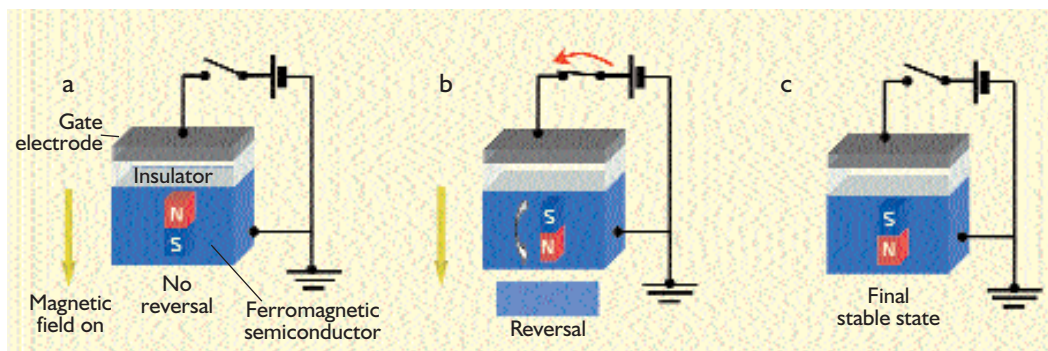
In a collaborative effort, researchers at Tohoku University in Sendai, Japan, and the Japan Science and Technology Corp. facility in Sendai have devised a way around this limitation. The team uses a combination of an electric field and a weak magnetic field in an innovative memory device to flip the magnetization direction in a semiconduct-

ing ferromagnet (*Science* 2003, 301, 943).

The device contains a manganese-doped indium arsenide ferromagnetic semiconductor, which is a channel layer in a field-effect transistor (FET). "We use an electric field to temporarily reduce the magnetic field needed to cause magnetic reversal," explains Hideo Ohno of Tohoku University's Research Institute of Electrical Communication. Such semiconductors are ferromagnetic only below a certain transition temperature (T_c). When a positive electric field is applied, it decreases the concentration of electron holes, which mediate the ferromagnetic interaction among the manganese atoms. The holes help to align the atoms' spins and create the magnetized state. As the team previously showed, the decrease in holes decreases the ferromagnetic material's T_c (see *The Industrial Physicist*, April/May 2001, pp. 16–17). And as the material's T_c gets closer to the temperature of the device, the magnetic-field strength needed to reverse magnetization also drops until a small negative magnetic field is enough to induce field reversal. This eliminates the requirement for large magnetic fields in writing heads.


After reversal, the electric field is removed, thus increasing the field needed for reversal (H_c). With a high H_c , the field is stable against thermal fluctuations. In experiments performed by the team, the H_c of the 4- to 5-nm-thick FET channel layer was reduced fivefold, from 10 to 2 G, with an applied field of 1.5 MV/cm.

The researchers used a material with a T_c of 33 K, but other semiconducting ferromagnetic materials have transition temperatures as high as 160 K. By increasing manganese concentration, the Japanese group expects to increase the transition tempera-



With the magnetic field on and the electric field off (a), no reversal occurs in the magnetic field of the ferromagnetic semiconductor until the electric field is turned on (b). With both fields turned off, the reversal is stable (c).

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ture to above room temperature. That feat will enable the integration of the devices into extremely small-scale transistors, pushing memory densities still higher. 

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