and his group at Carnegie-Mellon University have also been able to focus on successive layers and interfaces of thick production-line microelectronic components with a 150-MHz scanning acoustic microscope in the transmission mode. They report[4] that they can easily detect and characterize microscopic alloy spikes, inclusions, voids, and bonding defects too small to be spotted by arduous x-radiography. Microelectronic manufacturers have shown considerable interest in the potential for non-destructive quality control promised by such results coming out of the few labs with scanning acoustic microscopes. Though there exists a commercially available variant of the acoustic microscope, a non-focusing device known as a scanning-laser acoustic microscope (manufactured by Sonoscan Inc. of Bensonville, Ill.), which operates at 100–500 MHz, and employs a laser beam as the acoustic detector, microscopes of the kind developed by Quate are not yet available on the market.

For biological applications, the non-invasive nature of acoustic microscopy ought to make possible studies *in vivo*. At this early stage, Quate told us, when his group is still surveying the opportunities opened up by the newly achieved resolution, their cellular studies have been done mostly with "fixed" (non-living) cells. But with their present scanning rate, they may soon be able to study life processes at the cellular level. Quate points out that elasticity may be a useful indicator in living tissue. There is evidence that the velocity of sound is increased in malignant tissues. The time dependence of the elasticity of red blood cells may be useful for studying various types of anemia by acoustic microscopy. Kumar Wickramasinghe of the Stanford group has been able to detect the doubling of the DNA content of ovarian cells prior to cell division.

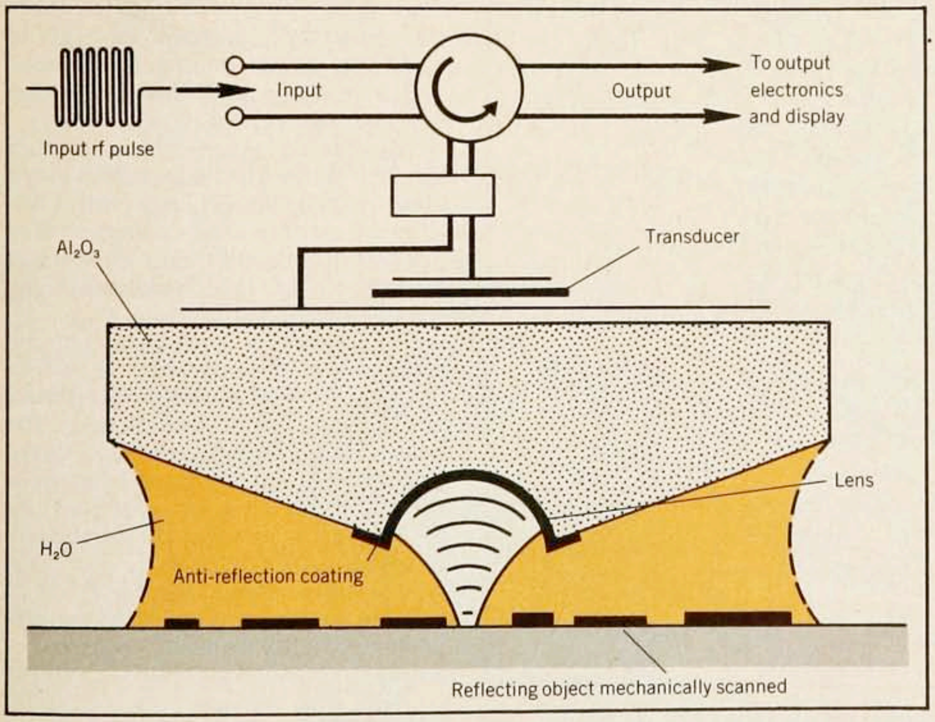
Photoacoustic microscopy. Quate's group recently published the results of their first experiment with a new kind of hybrid acoustic microscope developed by them.[2] In this photoacoustic microscope, the acoustic detector is the same sapphire lens plus transducer described above, but the acoustic source is replaced by a mode-locked laser, heating the sample with a 210-MHz train of 0.2-nanosecond light pulses. The sample surface is heated by absorbing light from the laser pulses, and the resulting periodic thermal expansion generates sound waves at 210 MHz and higher harmonics in the sample. By tuning the detecting transducer to 840 MHz, the Stanford group was doing its microscopy at the third harmonic of the laser pulse frequency. The size of the laser spot is comparable to the sound wavelength in water; so it does not seriously degrade the resolution of the microscope.

In photoacoustic microscopy, the sound wave serves primarily to detect the physical phenomenon of primary interest, namely light absorption at a given optical (as distinguished from modulation) frequency. The strength of the acoustical signal is a measure of the amount of light absorbed at a particular microscopic spot in the sample. Light absorption properties can serve as characteristic signatures of different materials. Therefore, by comparing the results of scans with different optical frequencies, one can detect the location of microscopic concentrations of particular substances.

Quate told us that he hopes to be able to locate DNA in cell nuclei by this technique, taking advantage of the 260-nanometer absorption band characteristic of the DNA molecule. One could also stain living cell structures at a level low enough to do no harm, but sufficient to cause observable absorption at the color of the stain. Quate believes that the laser power levels needed to generate detectable acoustic waves in these biological applications would not damage the living cells. For microelectronic applications, one could probe substrates of microcircuits by choosing optical frequencies to which the obscuring layer is more or less transparent. This would be useful for example in the microscopy of silicon structures epitaxially grown on sapphire crystals. —BMS

References

1. V. Jipson, C. F. Quate, Appl. Phys. Lett. 32, 789 (1978).
2. H. K. Wickramasinge, R. C. Bray, V. Jipson, C. F. Quate, J. R. Salcedo, Appl. Phys. Lett. 33, 923 (1978).
3. R. D. Weglein, R. G. Wilson, Appl. Phys. Lett. 31, 793 (1977).
4. C. S. Tsai, S. K. Wang, C. C. Lee, Appl. Phys. lett. 31, 317 (1977).



Scanning acoustic microscope used at Stanford in the reflection mode. The transducer imparts to the sapphire lens a 3-GHz acoustic input signal in 20-nanosec pulses and picks up the reflected signal from the scanned object. The lens has a focal length of 45 microns and is covered by a thin layer of glass. The resolution of the microscope is half a micron, the wavelength of 3-GHz sound in water. The object is moved in a raster pattern of several hundred lines per frame, and the output is displayed on a cathode-ray screen at several frames per second.

Limit on space isotropy improves thousandfold

One of the fundamental postulates of the special theory of relativity is that the speed of light is uniform in all directions, and is independent of the motion of the emitter or the observer. A recent report[1] from the Joint Institute for Laboratory Astrophysics (National Bureau of Standards and the University of Colorado) in Boulder has greatly increased the precision with which we know that the postulate agrees with experiment.

The fundamental experiment to confirm the postulate is, of course, the Michelson–Morley experiment. The new experiment, which was performed by A. Brillet of the Laboratoire de l'Horloge Atomique (Orsay) and John L. Hall of JILA, in principle measures the same effect, but it differs somewhat in details. In particular, the experiment's extremely high sensitivity depends on high-precision stabilized-laser techniques pioneered by Charles H. Townes and Ali Javan at MIT and developed, among others, by Hall.[2] The new work extends the null result by a factor of 4000 below that found earlier by T. S. Jaseja, Javan, J. Murray and Townes[3] in an experiment done with two lasers mounted at a right angle to each other on a rotating table.

In their experiment, Brillet and Hall essentially monitor the time it takes light to traverse a single Fabry–Perot etalon of fixed length, mounted on a slowly rotating turntable. The light source is a helium–neon laser, operating at 3.39 microns, that is also on the turntable. A servomechanism adjusts the operating frequency of the laser to maintain the boundary conditions at the etalon, so that the frequency of the laser is held to be a fixed submultiple of the round-trip transit-time for light to go through the etalon. A traditional interference experiment would then produce beats between the light from this etalon and the light from another oriented at right angles to it. Brillet and Hall, however, looked for frequency variations of the output of the rotating laser-interferometer combination. Because of the servo, any variations in the length of the etalon, or in the speed of light as it traverses the etalon, appear as frequency changes of the laser. As a frequency standard they used a second He–Ne laser, fixed in the laboratory, that was carefully stabilized to a saturated absorption line in low-pressure methane vapor. The figure shows a sketch of the important parts of the apparatus.

Results. In practice, the experiment is much more complex than described above. To ensure isolation of the two lasers from each other and to avoid direct feedback from the interferometer to its laser, Brillet and Hall took numerous precautions. From diagnostic experiments, Brillet and Hall estimate that the rotating laser has a frequency noise of about 20 Hz for a 1-sec measurement and that the frequency-stabilized laser is stable to within about 3 Hz over at least 20 minutes. Javan had high praise for their work, saying that they have pushed laser-stabilization techniques to the limit.

To make the frequency comparison, the beam from the stabilized laser is split and sent up along the axis of the platform to interfere with the output of the frequency-stabilized laser. Any variation in the time for light to traverse the etalon that depends on the orientation of the turntable should appear as a variation in the beat frequency between the two lasers at twice the rotation frequency (one turn in 13 sec).

Brillet and Hall, in fact, did observe a small Fourier component with the correct period in the beat frequency. However, the phase of this Fourier component remains constant in a laboratory frame. When the measurements are referred to a frame oriented with respect to the fixed stars, the phases of the individual points range over 2π, and the overall average of the variation due to any true spatial anisotropy becomes negligibly small. The final result of their experiment is a fractional frequency shift of $(1.5 \pm 2.5) \times 10^{-15}$ attributable to an "aether drift."

Because of the extreme sensitivity of the experiment, Brillet and Hall observed an effect at the fundamental rotation frequency that they attribute to a slight tilt of the turntable axis. The gravitational stretching and contraction of the Fabry–Perot etalon as the tilted turntable turns could account for the observed effect if the tilt were as small as a microradian (a fraction of a second of arc). James E. Faller, a colleague of Hall's told us that there is at least one known and uncontrollable source of tilt: Even though the experiment is done in an underground lab designed to be isolated from the JILA building, the laboratory floor shifts in the course of a day as the Sun warms up one side of the building. One suggestion to eliminate this effect is to move the experiment into one of the abandoned underground mines near Boulder, Peter Bender, a collaborator of Hall's, told us.

The source of the residual effect mentioned above, at twice the rotation frequency and with constant phase in the lab frame, is as yet unclear.

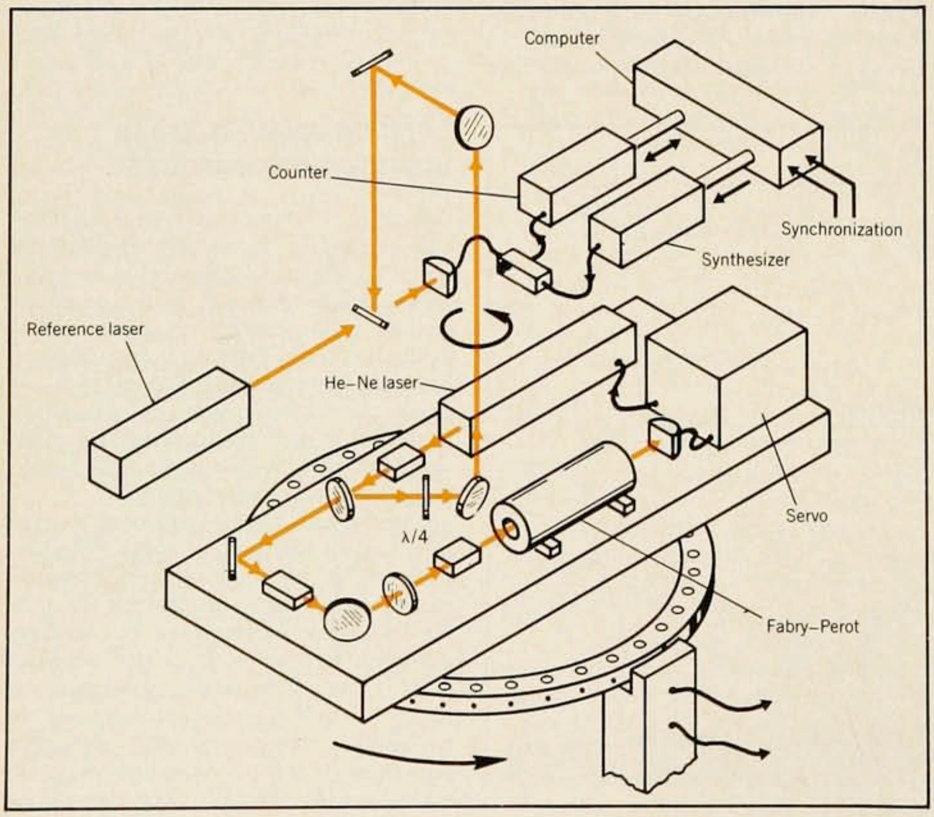
Interpretation. The JILA experiment attempts to measure a spatial anisotropy of the propagation of light. If one writes the invariant space–time element in a moving coordinate system whose x-axis is parallel to the velocity as

$$ds^2 = g_0 c^2 dt^2 - [g_1 dx^2 + g_2(dy^2 + dz^2)]$$

the experiment measures the ratio of g_2/g_1. In special relativity, of course, $g_2/g_1 = 1$. The quoted result differs from unity by $(1.5 \pm 2.5) \times 10^{-15}$.

Together with other experiments, such as the Kennedy–Thorndike experiment—which measures g_i/g_0 with a Michelson interferometer having arms of unequal length—the new experiment serves to confirm the foundations of special relativity.

The experiment is not be be confused with recent results measuring the velocity of the earth with respect to the cosmic microwave (3-degree) background. The Brillet–Hall experiment sets limits on the anisotropy of space-time as reflected in the coefficients of the laws of physics. As far as we know, however, the Earth's motion with respect to the microwave background is an accidental effect having to do with the initial conditions of the universe and not with the laws that govern its behavior. —TVF



The interferometer and related apparatus used to confirm that light propagates isotropically. The servomechanism adjusts the frequency of the laser on the turntable to maintain a constant number of standing waves in the Fabry–Perot etalon. Three Faraday isolators (starred) serve to prevent optical feedback between the etalon and the laser. Part of the output of the laser is circularly polarized and sent up along the axis of the turntable; its frequency is then compared with that of a methane-stabilized reference laser. Marks on the turntable provide pulses to enable one to examine only those frequency variations that have the same period as the table rotations.

References

1. A. Brillet, J. L. Hall, Phys. Rev. Lett. **42**, 549 (1979).
2. J. L. Hall, Science **202**, 147 (1978).
3. T. S. Jaseja, A. Javan, J. Murray, C. H. Townes, Phys. Rev. **133**, A1221 (1964). □