defenses is also blurring for futuristic Air Force theater defenses that would rely on powerful chemical lasers to destroy missiles when their boosters are still firing. One, the Airborne Laser, would blast missiles from perhaps 300 kilometers away, using an oxygen-iodine laser mounted in the nose of a Boeing 747. Although such systems were heavily criticized as impractical during the Star Wars days, the prototype laser has made dramatic advances in the amount of power it can train on a target, according to sources both inside and outside the military. Testifying before the Strategic Forces subcommittee of the Senate committee on Armed Services in February, Lieutenant General Lyles said that a related program—the Space-Based Laser—could someday " 'thin out' missile attacks" in their early stages as part of a multiple-shot NMD.

Decisive encounter

NMD's centerpiece is a separate system: a hit-to-kill interceptor that would function much like Thaad. It would get an early warning of a missile attack from existing or upgraded early-warning radars deployed on America's coasts, as well as from satellites and a new X-band radar tailored for national missile defense. The kill vehicle would then be launched on a three-stage rocket to make an intercept at altitudes of hundreds of kilometers, in hopes of protecting all 50 states.

Those altitudes, high above the atmosphere, may make distinguishing targets from decoys much more difficult for an NMD than for Thaad. Radar-reflecting swarms of aluminum shreds, or "chaff," would float along with the warhead in space, where there is no air resistance to strip them away. "Decoys are a major problem for the sensors," says Gerold Yonas, a former SDI chief scientist who is vice president for systems science and technology at Sandia National Laboratory in New Mexico. In the nightmare scenario, the kill vehicle would confront a swarm of radar-reflective aluminized balloons looping through space, only one of which contains a nuclear warhead.

BMDO officials say they are learning how to sort out decoys, noting that infrared sensors on the NMD kill vehicles, which are being built by Raytheon Systems Co. of Tucson, Arizona, successfully picked targets out of a set of decoys in flyby tests over the central Pacific in June 1997 and January 1998. (Details are classified.) This summer's interception test will also include decoys, although the kill vehicle will be told which mock warhead is the "real" one.

Analysts worry, however, that no matter how sophisticated the sensors, an attacker could find a way to sneak a weapon of mass destruction past them. Early in its flight, an ICBM might release dozens of individual "bomblets," each containing a fearsome biological or chemical warhead, making an effective intercept impossible. Or a disguised ship could simply steam into a U.S. harbor and fire a small nuclear warhead from there. "It has always been very implausible to me that a rogue state would send one or two missiles over here; it would be suicide," says Kurt Gottfried, a Cornell University physicist and acting chair of the UCS. Ensuring that Russia's crumbling early-warning radar does not give false alarms, leading to an accidental missile launch, would be a better way to spend the money, he says, calling NMDs "an ass-backward way of looking at our priorities."

But if ballistic missile defense engineers hit a bull's eye with the summer test, the push to develop and deploy a national defense may be hard to stop. "I have zero doubt that the system will work, ultimately," says John Peller, vice president and program manager for the NMD team at Boeing Co., which last April won a $1.6 billion, 3-year contract to oversee NMD development.

Major Demidovich of the Air Force, who will direct the NMD test, explains that the summer intercept attempt will actually be two tests in one: the actual intercept and a simultaneous "shadow" test on computers, in which the interceptor will get fewer hints about the identity of the target. The shadow test will begin with the launch from Vandenberg in California of a surplus American ICBM—a modified, three-stage Minuteman II missile with the mock warhead and decoys atop it. The stages will burn for about a minute each, and then the target and decoys will separate, eventually hurtling to an apogee of 1600 kilometers before falling back toward Kwajalein, itself about 7000 kilometers west and slightly south of Vandenberg. Satellites, early warning radars, and finally a prototype X-band radar at Kwajalein will track the objects and attempt to pick the target out from among the decoys. In the shadow test, these data will be used to launch and guide a computer-simulated interceptor to its basket in space.

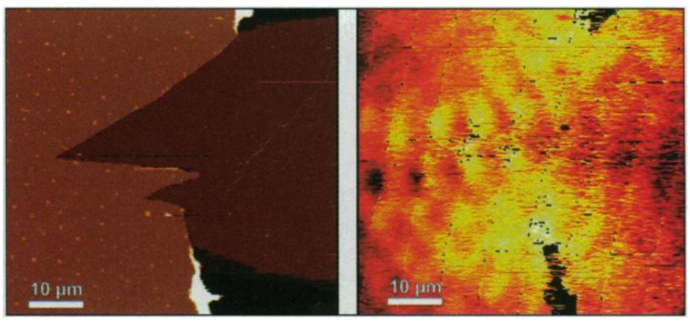
In the real test, which will unfold at the same time, another modified Minuteman II carrying the Raytheon kill vehicle will blast off from Kwajalein about 25 minutes after the launch of the "hostile" missile from Vandenberg. The vehicle will be dropped into its basket and use its infrared seekers to lock onto the mock warhead, firing thrusters for course corrections until, 230 kilometers above the ocean, the two objects violently collide and pulverize each other. Or they will sail silently past each other in space, leaving only questions behind. —JAMES GLANZ

ACOUSTICS

Probing the Shaking Microworld

With the help of atomic force microscopes, acoustics researchers are using vibration as a tool to study materials' elastic properties on a microscopic scale

Vibration is the bane of microscopy. When you are trying to image atomic-scale features using instruments such as the scanning tunneling microscope (STM) or the atomic force microscope (AFM)—which scan needle-fine tips across a sample—even the slightest vibration will smear the picture. For one group of researchers, however, vibrations are not a problem: They're the object of the exercise. At a recent acoustics meeting* in Berlin, several European research groups reported techniques that set a sample vibrating with sound waves and then use STMs or AFMs to sense how its atoms are jiggling about, revealing details of the material's local physical properties, such as elasticity.



Ripple image. Acoustic waves (*right*) in a gold layer (light brown) on quartz.

CREDIT: CHILLA *ET AL*/PAUL DRUDE INSTITUTE FOR SOLID-STATE ELECTRONICS

"We have demonstrated that it is possible to image oscillations on an atomic scale," says Eduard Chilla of the Paul Drude Insti-

* The Joint 137th Meeting of the Acoustical Society of America and the 2nd Convention of the European Acoustics Association Integrating the 25th German Acoustics DAGA Conference, Berlin, 14 to 19 March.

tute for Solid-State Electronics in Berlin. Such studies are of more than academic interest. Communications equipment, televisions, and cellular phones regularly rely on acoustic transducers as filters to exclude unwanted signal around their desired frequencies. Understanding how these devices vibrate can help improve their performance.

Researchers wanting to trace sound waves in a material have generally been limited to coarse images of low-frequency waves. One strategy is to bounce pairs of laser beams off the material's surface and then combine the beams to produce an interference pattern, which indicates how the sound waves are displacing the surface, but the lasers' spot size limits the resolution of the technique. "It is almost impossible to image [high-frequency] waves" that are key to devices such as cellular phones, says Chilla.

But a collection of six European teams known as the Atomic Force Microscopy and Microacoustics consortium, which has been supported by European Union funding, is probing vibrations on a much smaller scale. Under the right conditions, an AFM tip placed near a vibrating surface will stick to it, because of van der Waals and other electrical and viscous forces, causing the tip to follow the surface's oscillation. The tip's motion is read out by bouncing a laser beam off a tiny mirror attached to the cantilever. By pumping ultrasound into a material at different frequencies, then imaging the passing waves, researchers can determine the material's velocity dispersion—the relationship between the waves' velocity and their frequency—which is a clue to its elastic properties on a nanometer scale. This allows the detailed study of how the very small structures found in acoustic filters behave when vibrating and how the different parts influence each other.

Chilla's team is now trying to image the motion of an individual atom as the sound oscillation moves it through an elliptical path. Above frequencies of around several hundred kilohertz, the probe tips just can't keep up. Chilla reported at the Berlin meeting, however, that he and his team can still glean information on high-frequency waves by allowing the tip to skim the surface of the waves, registering their amplitude without following their every up and down. From this information the researchers can derive the local elastic properties of the material at high frequency.

In a variation on this technique, Andrew Kulik and his group at the Swiss Federal Polytechnic Institute in Lausanne eliminated adhesion from the equation. Relying on adhesion to couple the tip and the surface can skew measurements of elasticity, because the adhesive bond between the tip and the material can also stretch and compress. So Kulik's team holds the tip absolutely steady and lets the oscillating surface bump into it. Analyzing how the tip vibrates when it touches the vibrating surface reveals the local elasticity. "We have a depth resolution of about 100 nanometers, and we know that we are imaging elastic properties," says Kulik.

Similarly, a team led by Walter Arnold of the Fraunhofer Institute for Nondestructive Testing in Saarbrücken, Germany, actually pokes the tip into the surface so that it moves with it. "You deform the surface with the tip, and the deformation field contains the stiffness of the tip and the sample," says Arnold. If you know the stiffness of the tip, you can deduce the elasticity of the sample, he explains. The system is so sensitive that it can detect differences in the elasticity in the small areas in magnetic materials in which the magnetic field is oriented in a specific direction. "The various domain orientations have a different contact stiffness," he says.

–ALEXANDER HELLEMANS

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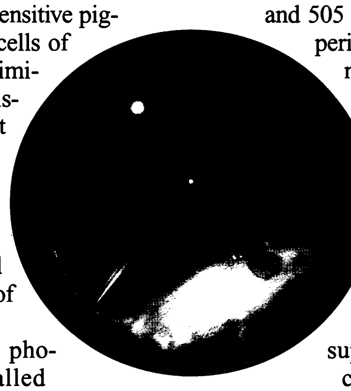
CIRCADIAN RHYTHMS

The Clock Plot Thickens

Researchers prove that a nonvisual light sensor sets our daily clock; a likely candidate for that role appears to fulfill other clock functions, too

One of our most indispensable biological machines is our circadian clock, which acts like a multifunction timer to regulate sleep and activity, hormone levels, appetite, and other bodily functions with 24-hour cycles. The clock generally runs a bit fast or slow and must be reset daily by sunlight. Although many components of the clockwork are known, the crucial photoreceptor that passes light's signal to the clock is still at large.

Two suspects, the light-sensitive pigments in the rod and cone cells of the mammalian eye, are eliminated by two papers in this issue. "The really important conclusion from these experiments is that there is another photoreceptor" affecting the clock, says circadian biologist Michael Menaker of the University of Virginia, Charlottesville.



The eyes have it. The mammalian clock receptor, although not in the rods and cones, is in the eye.

CREDIT: T. JOYCE, M. FREEDMAN, R. J. LUCAS, AND R. G. FOSTER/IMPERIAL COLLEGE

One candidate for that photoreceptor is a protein called cryptochrome. But a report in yesterday's issue of *Nature* puts an intriguing wrinkle in that story, fingering cryptochrome as a likely part of the clock itself. In mice that lack cryptochrome, the group found, the clock doesn't run at all. "We have never seen [in mice] a mutant like this, where there is instant arrhythmicity," says clock researcher Steve Kay of The Scripps Research Institute in La Jolla, California. That means cryptochrome is essential for clock function, but leaves open the question of whether it is the long-sought circadian photoreceptor in mammals.

Biologists have known since the 1960s that the clock-setting light signal in mammals normally comes via the eyes, because eyeless rodents and humans with few exceptions are unable to reset their clocks to light. One obvious possibility is that the molecules that capture light for vision—the opsins in the rod and cone cells of the retina—also send light signals to the clock.

Evidence against that has mounted as researchers have found that mice lacking either rods or cones have clocks that respond to light. But the chance remained that rods and cones both can do the job, and either can do it alone. The reports on pages 502 and 505 by Russell Foster of the Imperial College of Science, Technology and Medicine in London and his colleagues rule that out.

The researchers introduced genes that destroy retinal rod and cone cells into mice. They found that in those mice, just as in normal mice, light resets the clock and suppresses production of the clock-controlled nocturnal hormone, melatonin. "That says that you don't need rods and cones" for the light response, says Menaker, and means another photoreceptor must do the job.

Cryptochrome, which is found in the eye, became a hot candidate for the photoreceptor last fall, when three teams reported that it seems to help light reset the clock in plants, fruit flies, and mice (*Science*, 27 November 1998, p. 1628). A group led by Aziz Sancar at the University of North Carolina, Chapel Hill, and Joseph Takahashi at Northwestern University in Chicago mutated *cry2*, one of two mammalian cryptochrome genes, in mice. The animals' clocks lost some light responsiveness, suggesting that Cry2 is a light sensor, but not the only one. Researchers wondered if Cry1 might be the other, and