T Rays for Two

Terahertz waves give rise to a new imaging technique

By RICHARD LIPKIN

Photos: Hu, Nuss/AT&T Bell Laboratories

T rays can map the fat in meat, which appears nearly white in this slice of bacon.

They had set out to work on an entirely different problem. Bin Bin Hu and Martin C. Nuss, two physicists at AT&T Bell Laboratories in Holmdel, N.J., aimed to develop a better method for testing the integrity of high-speed electrical circuits.

But noting how easily terahertz waves—a form of trillion-cycle-per-second radiation that exists between the infrared and radio wave regions of the spectrum—penetrate the silicon circuitry, the scientists began to wonder about more general applications. Could this technique be used to determine the structural and chemical compositions of ordinary objects?

Indeed it can, they soon confirmed.

Thus emerged a new imaging system bearing the name T rays.

"This is one of those cases," says Nuss, "where we set out to do one thing and ended up finding something completely different that's more important."

"You can think of terahertz waves as very high frequency radio waves or very low frequency infrared waves," says Nuss. "These waves have the interesting property that they can easily pass through many dry, nonmetallic materials, like plastic, cardboard, wood, and glass."

Although the radiation can penetrate only a few millimeters into some materials, the waves can pass through sufficiently thin samples, becoming slightly distorted in the process. By interpreting the changed wave forms that emerge from the other side, researchers can figure out the chemical composition of the material in question.

By measuring subtle distortions of the T rays, including absorption, dispersion, and reflection, scientists can decode the wave form "signatures" characteristic of specific elements. Conventional far-infrared spectroscopy yields similar compositional information, but it cannot produce an image. In the new technique, a computer formulates compositional data into a color picture.

Nuss and Hu found that terahertz waves passing through the fatty edges of a bacon slice, for example, come out looking quite different from those making their way through the meaty middle.

Surprisingly, the same signal-processing algorithms that the telephone company designed for speech recognition have come in handy for decoding terahertz waves. Once the T rays have gone through a substance, a device can capture them on the other side, treat them as if they were audio signals, and listen, in a manner of speaking, to the changes that took place.

Analyzing the terahertz waves, the signal processor then determines the distribution of the chemical compounds in the material and creates a compositional picture of the object with a resolution of 250 micrometers. The researchers reported their findings in May at the Conference on Lasers and Electro-Optics held in Baltimore.

By merging the advantages of optical and electrical probes, the new T-ray imaging system enables scientists to chemically analyze an object—revealing, for instance, whether a sealed package contains a banana or a bomb.

"We've looked through industrial objects and plastic packages and seen the circuitry inside of an electronic card," said Nuss. "We put a business card inside a sealed envelope and read the letters."

Because metals absorb T rays completely, they cannot be imaged by this technique, but water partially absorbs the radiation and shows up clearly in T-ray images, says Nuss. "For instance, we can look at a leaf or a piece of fruit and see the distribution of the water inside. You can tell how fresh it is, whether it's drying out. You can also find the fat in meat. Looking at a slice of bacon or a piece of marbled beef, you can see the fat content."

The system has proven particularly adept at figuring out the composition of gases. "In this frequency range, gases tend to have very strong, narrow absorption lines. So, for example, you can tell if you're looking at a cylinder filled with carbon dioxide or carbon monoxide. It's quite specific," Nuss observes.

Nuss believes that T-ray imaging may be useful for monitoring industrial gases or pollutants, and for quality control in semiconductor manufacturing.

Although scientists have experimented with terahertz waves for many years as a probe for electrical equipment, no one had previously attempted to use them for imaging. Among other problems, the type of electronics necessary to propagate such waves proved too cumbersome and costly for common use.

Now, the burgeoning of shoe-box-size, solid-state lasers capable of firing off accurate, ultrashort bursts of energy has made T-ray imaging systems more practical.

"From a technological point of view, T rays are tricky to produce," says Nuss. "There are no electrical systems fast enough to generate terahertz waves directly, so we use laser pulses instead." A fast laser pulse directed at a solid-state device excites terahertz oscillations, generating the desired waves. The kind of solid-state laser used produces pulses that last only 100 femtoseconds, or one-tenth of a trillionth of a second—just enough time to produce, detect, and measure a T-ray burst.

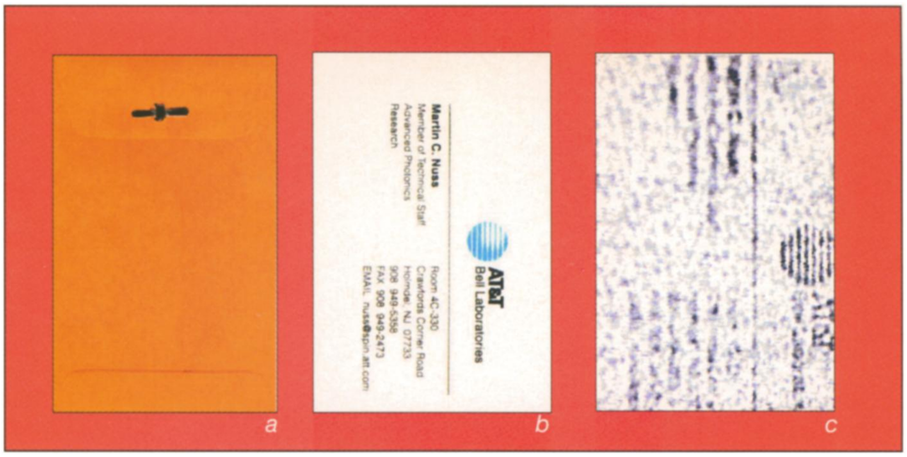
"Terahertz waves are particularly interesting because they occupy a region of the spectrum where optical and radio waves overlap and hence classical and quantum physics intersect," says David A. B. Miller, a physicist at Bell Labs. "You can think of them as radio waves generated by antennas or as photons generated quantum mechanically."

"From the physics point of view," Miller continues, "that's a very intriguing property. In fact, our desire to understand some of the fundamental physics of terahertz waves forced the technology to advance enough to make imaging possible."

"It's hard to say what will ultimately come out of this," says Jeffrey Bokor, a physicist at the University of California, Berkeley. "You never really know in advance. But this is very creative, thought-provoking work."

Bokor thinks that Nuss may be underestimating the potential applications of the technique. "Traditionally, this region of the electromagnetic spectrum has been difficult to work in, so people have avoided it. But now that we're seeing new technologies for handling this type of radiation, unanticipated applications will undoubtedly emerge," he says.

"This is an interesting example of science." Bokor muses. "Nuss starts out looking at pulse propagation in semiconductors, and the next thing you know, he's looking at slabs of bacon."



T rays pass through a sealed envelope (a), revealing an enclosed business card (b) and generating an image of the card (c).

Now that word has gotten around, colleagues are wandering into Nuss's laboratory with all kinds of ideas for applications of T-ray imaging. Thoughts range from searching skin or tissue samples for cancer cells to looking for chocolate chips inside cookies. Because T-ray imaging excels at finding objects just below dry, nonmetallic surfaces, at locating hidden water deposits, and at distinguishing gaseous emissions, potential practical uses crop up in arenas as diverse as screening computer circuits and chimney flues to checking out fruits and vegetables for freshness or fat content.

The military might find uses for it in radar or remote-sensing systems. In quality control, one could, in theory, scan fabrics, car parts, or building materials for manufacturing flaws. A homeowner might scan dry walls for wet insulation, structural beams, or perhaps water dripping from a hidden plumbing leak. Peering into sealed packages poses other opportunities. Presumably, a company could check a product's integrity before shipping, while mail handlers could search letters for explosives.

"We're still trying to get a feeling for this technology's strengths and weaknesses," says Nuss. "We're asking the question: What can this technique do that other imaging techniques can't do? That's the most important work to do at the moment, before worrying about commercializing it."

Puzzling over spin-off technologies that T-ray systems might spawn, Miller recalls the startled reaction of a colleague at the Baltimore conference when Nuss displayed an image of the contents of a sealed envelope.

"He turned to me and said, 'There may a new market out there for foil-lined envelopes.' " □

Technology

A silicon chip with a lot of nerve

The science fantasy of computers that send signals straight to a brain has taken a small step toward reality.

Peter Fromherz and Alfred Stett, physicists at the Max Planck Institute of Biochemistry in Munich, have made a silicon chip that can directly stimulate a nerve cell. Their so-called silicon-to-neuron junction, reported in the Aug. 21 PHYSICAL REVIEW LETTERS, triggers a single nerve cell in a leech without killing the cell.

"It is possible now to interface individual neurons with silicon microstructures in both directions," they say, "from silicon to neuron, by stimulation of a [membrane] spot, and from neuron to silicon, using a metalfree field effect transistor."

In previous artificial nerve stimulators, metal leads tended to corrode and shed toxic by-products. In contrast, the silicon chip propagates a voltage pulse from a tiny spot on the cell membrane. This causes a buildup of positive charge that trips a neuronal impulse.

The new chip complements "neuron transistors" that receive ionic nerve impulses, transforming them into an electric impulse on a silicon chip. Together, the two microstructures offer the possibility of direct, two-way communication between a nervous system and machinery.

Still, employing the device for medical purposes—to control an artificial limb, for example—lies far in the distance, the scientists conclude. Exactly how practical it will prove, they say, "remains to be seen."

Stealth surgery on brain tissue

A robotic arm, guided by a computer programmed with missile-tracking software, can now deliver pinpoint doses of radiation to tumors in highly sensitive areas of the body, such as the brain and spinal cord.

The extreme accuracy of the system may make it possible to treat on an outpatient basis some cancers that are not amenable to surgery, says John Adler, a neurosurgeon at Stanford University Medical Center.

Called computer-mediated stereotaxic radiosurgery (CMSR), the new technique combines software adapted from Cruise missile guidance systems with robotic manipulators and a high-powered X-ray machine.

Before surgery, a CAT scan generates a detailed three-dimensional map of the target. The robotic arm then compares its own X-ray images with the mapped target, tracks and locks onto a tumor, and delivers a dose of radiation without harming surrounding tissues, says Stanford physicist Richard Cox.

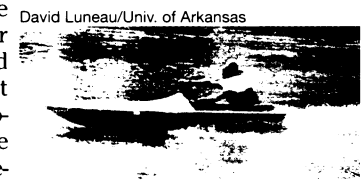
As a result, physicians may be able to kill off some types of cancers without opening a patient's skull or spine, Adler says.

Solar splash

An electric boat powered only by the sun sped across water recently at a record 25 miles per hour.

The Trojan Warrior, designed and built by engineering students at the University of Arkansas in Little Rock, sports an aluminum hull and an engine adapted from an industrial forklift. In last month's regatta on Lake Michigan, the craft, powered by solar cells and sun-charged batteries, raced 300 meters in 26.38 seconds. In a test of endurance, Golden Eagle, a hydrofoil built by Japan's Kanazawa Institute of Technology, traversed 30 kilometers in 2 hours.

David Luneau/Univ. of Arkansas



Solar-powered boat.