

T Rays for Two

Terahertz waves give rise to a new imaging technique

By RICHARD LIPKIN

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, ultra-short 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."

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.'" □