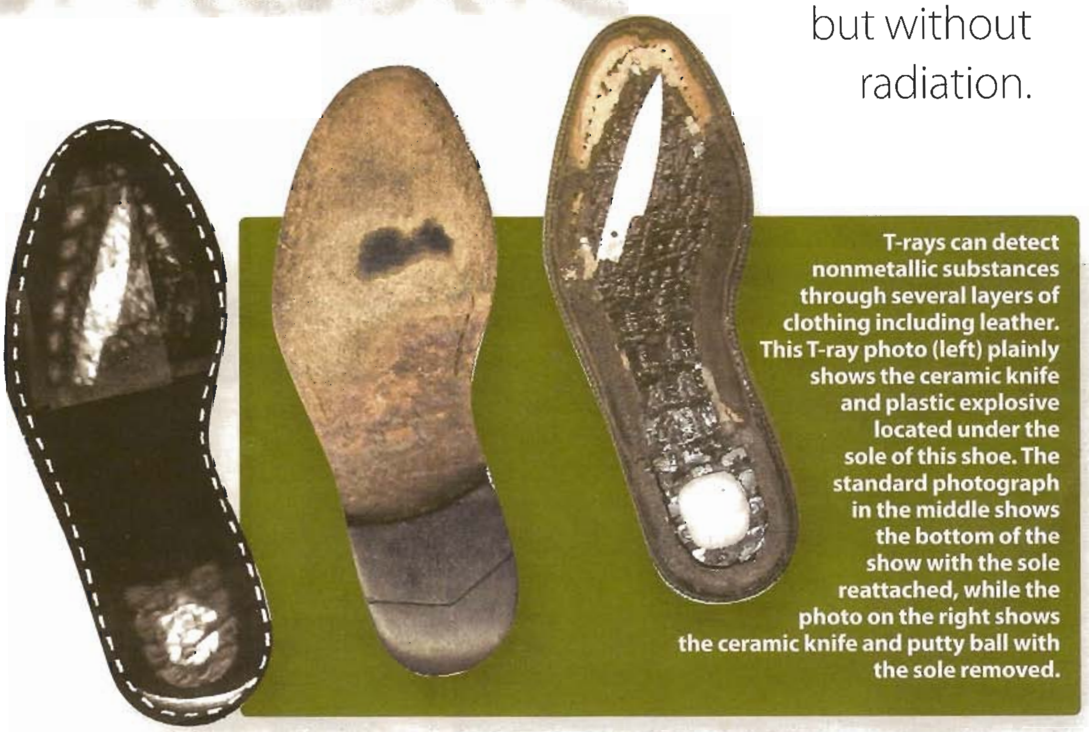
Shine the light fantastic

Think of terahertz light as a supercharged X-ray, but without radiation.



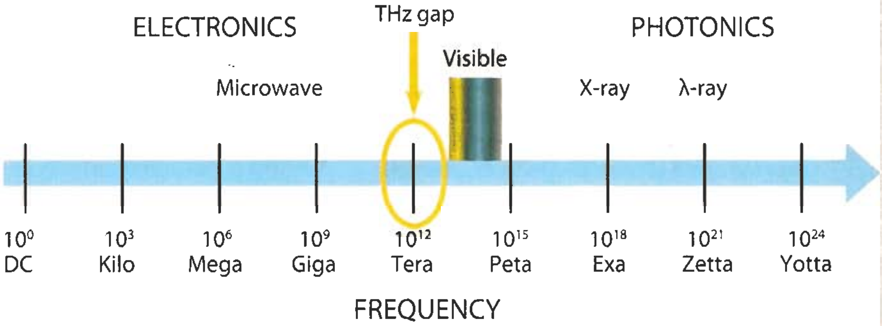
T-rays can detect nonmetallic substances through several layers of clothing including leather. This T-ray photo (left) plainly shows the ceramic knife and plastic explosive located under the sole of this shoe. The standard photograph in the middle shows the bottom of the show with the sole reattached, while the photo on the right shows the ceramic knife and putty ball with the sole removed.

There has long been a gap in the usable electromagnetic spectrum where radio waves end and infrared light begins. Called the Terahertz Gap, its name comes from the metric prefix that represents its frequency: tera. Tera means trillion, so terahertz represents frequencies in the trillions of cycles per second. Whether these waves represent radio or light is still open to conjecture. Some research groups refer to them as microwaves, while others prefer optical or photonic studies. There's no doubt, however, that the field of T-rays, as terahertz radiation is called, is just beginning to take off.

What makes T-rays so interesting is their interaction with regular matter. Like an X-ray, T-rays can penetrate many different types of matter to permit X-raylike imaging. Unlike X-rays, however, T-ray radiation is nonionizing, making it safe for long-term exposure. T-ray beams can be focused as one might focus light, and the reflection returns a signature or fingerprint capability called functional imaging. Molecules react to the T-ray radiation, adding their own vibratory, rotational, or translational response to the reflection. By analyzing the changes in the reflected waves, T-rays can identify the type of material being imaged in a form of spectroscopy. The synchronous frequencies of T-rays are much wider than those of X-rays, meaning T-rays respond to a wider range of materials.

This identification of materials comes in handy for security. A T-ray scanner can detect hidden threats that an X-ray scanner or magnetometer (metal detector) may

The Terahertz Spectrum



The terahertz band falls just below the visible spectrum of light but above microwave radio.

miss. For example, a ceramic knife can pass right through a metal detector without triggering an alarm. But ceramic becomes brightly illuminated under T-ray light and is easily detected, even through several layers of clothing or the sole of a shoe.

The ability of T-rays to identify materials also helps discern a female terrorist carrying a hidden explosive from a woman with a tube of lipstick. The explosive possesses a different molecular signature that the T-ray imager can detect.

With all of this capability, one might wonder why T-rays aren't more widely used? Two problems plague the widespread adoption of T-ray imaging. First is finding a way to generate enough light in the T-ray frequency band. The second is how to create a detector sensitive enough to react with the T-ray beam and having resolution high enough for imaging. Research programs around the globe search for these answers. And there have been some interesting solutions forthcoming.

One method of generating light at terahertz frequencies is through a free-electron laser or FEL. The **Thomas Jefferson National Accelerator Facility** in Newport News, Va., has generated terahertz light 10,000× brighter than any other source. The researchers there, along with scientists from **Brookhaven National Laboratory** in Upton, N.Y., and **Lawrence Berkeley National Labo-**

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Key points:

- T-rays penetrate clothing and other materials but at lower energy levels than X-rays, making them inherently safer.
- T-rays can act as a spectroscope, reporting the type of material being scanned by molecular absorption of specific T-ray frequencies.
- The major drawback to T-ray adoption is the development of an effective light source and detector.

Resources:

Cambridge Consultants, *http://tinyurl.com/yz3d7a9*

Center for Terahertz Research, Rensselaer Polytechnic Institute, *http://www.rpi.edu/terahertz/*

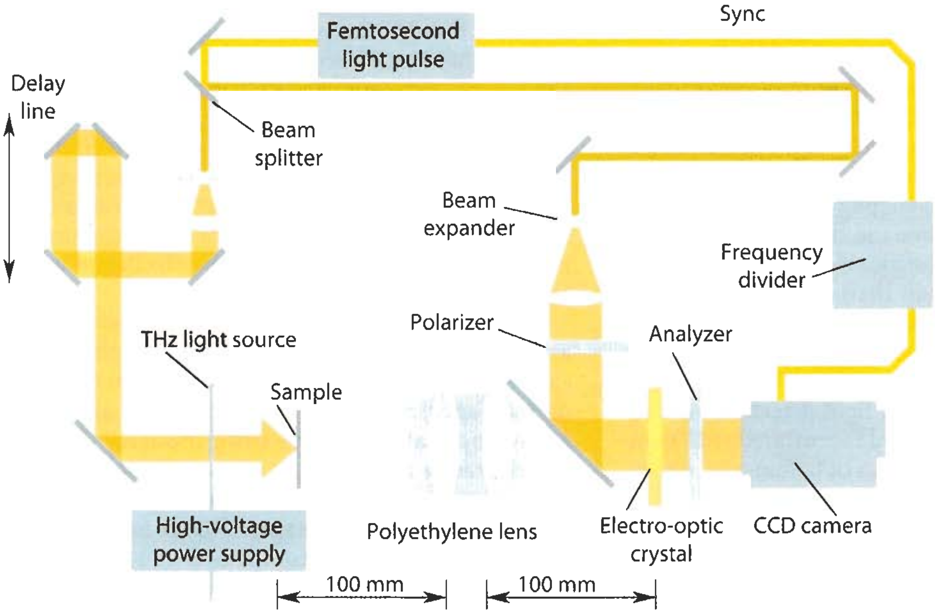
Jefferson Lab, *http://www.jlab.org/FEL/terahertz/*

Nikon Corp., *http://tinyurl.com/yjgvkv7*

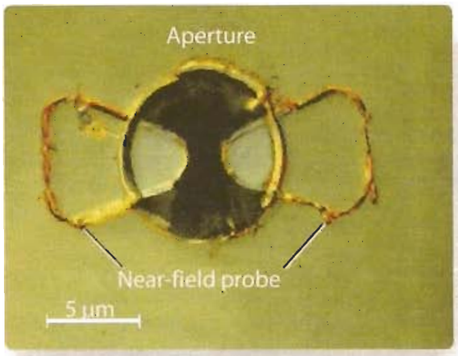
Riken, *http://www.riken.go.jp/engn/*

TeraView, *http://www.teraview.com/terahertz/terahertz.html*

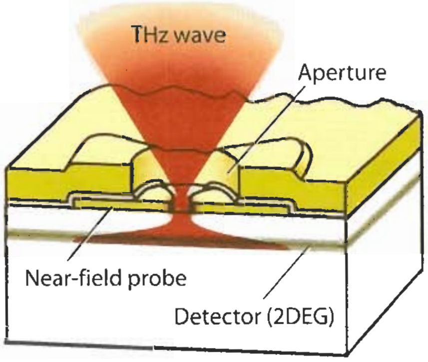
Terahertz light source and imaging



This diagram shows the optical imaging system of the Rayfact-RIM-001EX real-time imaging system by Nikon Corp. A femtosecond light pulse from a laser is used to generate the terahertz-frequecny light and to convert that light to an image the CCD camera can record using an imaging plate.



This optical micrograph (left) and schematic (below) shows a highly sensitive on-chip near-field THz detector. The aperture is 8 µm in diameter. The detector actually consists of a 2DEG electron gas located 60 nm below the chip surface. The chip material is gallium arsenide and aluminum gallium arsenide (GaAs/AlGaAs).



ratory in Berkeley, Calif., sent a beam of electrons at nearly the speed of light through a magnetic field called a wiggler. The electrons were accelerated through a superconducting linear accelerator (linac) and then fed into an optical cavity with the wiggler in its center. As its name says, the wiggler forces electrons to wiggle through the cavity giving up energy as light in the process. The light is reflected back by the optical cavity to induce new electrons entering the cavity to emit even more light, the way an optical laser bounces light between two mirrors to amplify its effect.

Up to this point, no other method of generating T-rays yielded more than a thousandth of a watt. The FEL-generated T-rays compared to those from other sources were described as a floodlight compared to a candle.

The Tera-photonics Team at Riken, a research think-tank in Japan, has another laser that plays a role in generating terahertz-frequency light. There researchers pass a green laser through a nonlinear optical crystal. The crystal's properties divide the green laser into two beams of near-infrared light of slightly different frequencies using a process called parametric oscillation. The two infrared beams then recombine in another nonlinear optical crystal which creates the terahertz light having energy equal to the difference in energy between the two IR beams. The resulting terahertz light is monochromatic, meaning it consists of only one frequency. But by changing the angle that the green laser strikes the first crystal, the researchers can change the frequency of the infrared beams thus changing the frequency of the terahertz light. Their installation can create T-rays from 1 to 40 THz, a critical need for substance identification.

A task even more difficult than creating a terahertz light source appears to be the creation of a terahertz detector having enough resolution for photographic imaging. One drawback is that terahertz light goes right through most materials used for light detection. As terahertz frequencies are considered far infrared (FIR), initial detectors used FIR techniques of bolometric, photonic, and plasmonic detection.

Heating because of absorbed FIR changes the conductivity of bolometric semiconductors. However, bolometric sensors are not sensitive to frequency differences — a key element in substance identification. Photonic detectors, such as resonant tunneling diodes, can detect different frequencies. But they are typically overcome by bolometric effects that mask the sensitive readings.

The ideal detector would be based on a chip, similar to the CCD imagers used in digital cameras. But standard silicon is useless as T-rays pass through silicon the same way that visible light passes through glass. Nanoelectronic technologies may hold the key to creating usable T-ray detectors.

One such device is a carbon-nanotube (CNT) quantum dot (QD). Quantum dots are unique because they are so small, ranging from 2 to 10 nm (10 to 50 atoms) in diameter. It's possible to fit 4 million dots in a straight line across the width of a penny. When a CNT-QD is hit with terahertz light, it changes the amount of current traveling through the nanotube in proportion to the strength of the light. Right now CNT quantum dots must be cooled to work properly. But the researchers are confident room-temperature CNT-QD detectors are likely. Eventually, it should be possible to produce a T-ray imager made from millions of these CNT quantum dots that behaves like a CCD.

Nikon Corp. researchers came up with a different technique for detecting T-rays that does use a CCD. In this case, though, they convert the T-ray light source to visible light using a laser. The T-ray light passing through a test sample strikes an imaging plate, changing the plate's refractive index based on the strength of the light. A laser scanning the plate transfers the refractive change into visible light that's imaged by a CCD camera capable of taking 30 fps. By using 1-psec bursts of terahertz radiation and synchronizing the camera image capture, it was possible for the first time to capture the light-wave front as it impacted the imaging plate.

Today, special applications in terahertz imaging are emerging in medical equipment and pharmaceuticals. Short-pulse terahertz systems are used as a time-domain spectroscopy to look at biological processes. Many applications in the drug industry don't need a wide-range frequency response, but can get by on several key reference points to nondestructively verify capsule contents and dosages. There's no doubt that as light sources and detectors continue to improve and the science matures, terahertz technologies will continue to find new applications. **MD**