Computed tomography adds third dimension to terahertz imaging

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Unlike traditional x-ray CT, which only measures the amplitude of the transmitted radiation, t-ray CT measures the transmitted pulse shape to reveal more information about the sample.

Terahertz radiation occupies a large portion of the electromagnetic spectrum between the infrared and microwave bands from 0.1 to 10 THz. This frequency range presents the next frontier in imaging science and technology. Compared to the relatively well-developed imaging techniques at microwave and optical frequencies, however, basic research, new initiatives, and advanced technology developments in the terahertz band are very limited. The “THz gap” is a scientifically rich but technologically limited frequency band—largely because efficient terahertz emitters and receivers are a relatively recent invention.

For just over a decade terahertz time-domain spectroscopy has been used to determine the optical properties of materials in the submillimeter wavelength regime. More recently, two-dimensional terahertz imaging has been demonstrated for a diverse range of applications including imaging semiconductors, leaf moisture content, flames, skin burn severity and skin cancer.1,2

Terahertz imaging is attractive for several reasons: the radiation is nonionizing and poses very few safety risks, it is capable of submillimeter resolution and, significantly, several materials, including paper, plastics, and cardboard, are relatively transparent in this frequency band. Conventional terahertz imaging techniques, however, cannot determine the three-dimensional (3-D) structure of objects.

Terahertz computed tomography (t-ray CT) is a new tomographic imaging modality that allows pulsed terahertz radiation to probe the optical properties of 3-D structures.3 It provides sectional images of objects in a manner analogous to conventional computed tomography techniques such as x-ray CT. Terahertz CT systems directly measure the transmitted amplitude and phase of broadband terahertz pulses at multiple projection angles through a target, which allows a wealth of information to be extracted from the target object, including both its 3-D structure and its frequency-dependent far-infrared optical properties. It extends the capabilities of previous t-ray tomography systems by allowing more general 3-D targets to be imaged.4

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FIGURE 1. A hollow dielectric sphere is imaged using t-ray CT. The sphere is attached to a plastic tube, which is rotated by the rotation stage. The sphere was scanned with a 1-mm step size and the terahertz image was obtained for 18 different projection angles.
The reconstruction of the 3-D object from the measured projection data is performed using mathematical inverse algorithms. Terahertz CT borrows algorithms from x-ray CT. The filtered backprojection algorithm has long been the workhorse in this domain. It is used to invert the Radon transform to reconstruct the terahertz image.

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works well for targets with features that are large relative to the wavelength of the terahertz radiation (0.3 mm at 1 THz). However, for more complex targets with fine structure the filtered back-projection algorithm is unable to accurately reconstruct the target because diffraction effects dominate the measurements (see Fig. 3 and 4).

The future
The applicability of the t-ray CT technique is limited by two important restrictions: first, the limited terahertz power available and, second, the approximations made by the reconstruction algorithm. As t-ray CT operates in transmission mode it is only suitable for objects that do not attenuate or scatter the terahertz radiation too severely. This is a particular limitation for biomedical applications in which the absorption of moist tissue is prohibitive. In addition, the current simple reconstruction algorithm does not describe the full interaction of terahertz radiation with complex structures and more sophisticated methods are required before strongly diffracting objects can be imaged accurately. Fortunately, recent research is making progress on both these fronts. Applications of this technique are foreseen in nondestructive mail and packaging inspection, semiconductor testing, manufacturing quality control, and even potentially in some biomedical applications where the absorption of terahertz is not too extreme.

REFERENCES