# Algebraic reconstruction technique for 3-D imaging in the terahertz frequency range

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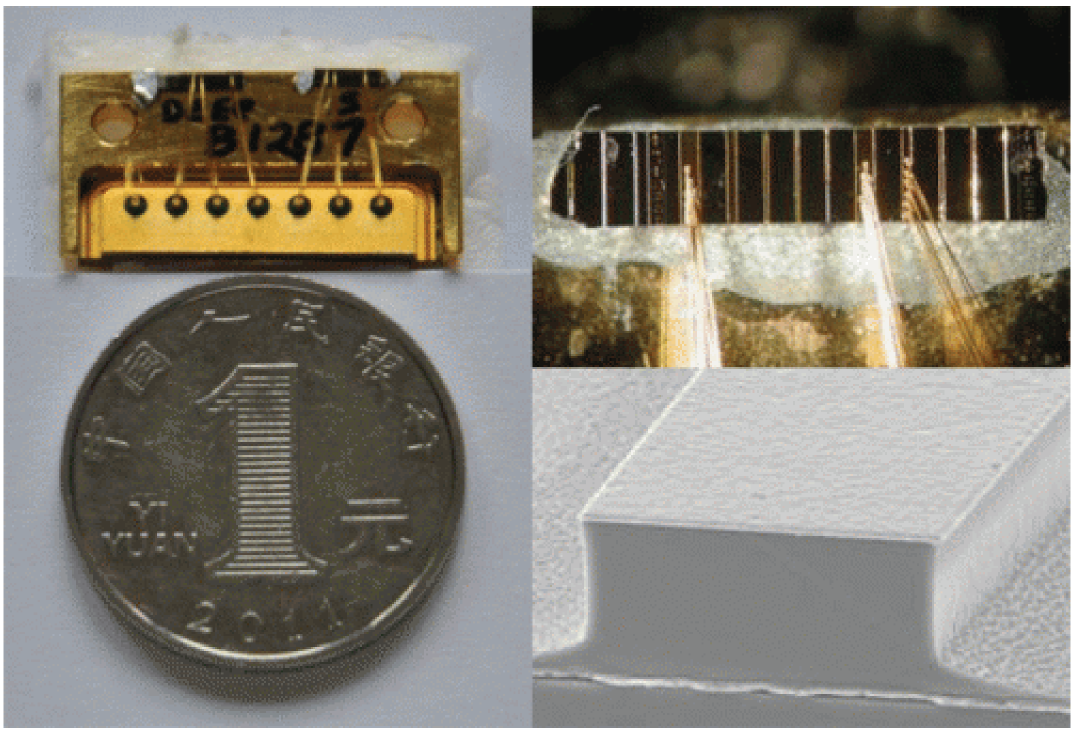


The team used techniques ranging from macroscopic to nanoscale to improve THz generation and detection for their imaging system

Researchers at the Shanghai Institute of Microsystem and Information Technology and Fudan University in China have used an algebraic reconstruction technique (ART) for 3D imaging in the terahertz frequency range. They developed their technique in conjunction with computerised tomography (CT) based on a THz quantum cascade laser

(QCL) and a quantum well photodetector.

## Two-to-one

CT was first developed in the X-ray frequency band to reveal the cross-sectional image of an object by combining the different projections from different angles. The basic principle of CT relies on the Fourier-slice theorem, which states "that if the projections of each angle of a 2D image are obtained, the pixel value for any point can be calculated," explained Tao Zhou, lead author of the research. From a more mathematical standpoint, he said, "the 1D Fourier transform of a parallel projection of an object is a line of the 2D Fourier transform of the object."

Extending CT into the THz band was first achieved using time-domain spectroscopy (TDS). In these systems, THz pulses are generated using a femtosecond laser and a photoconductive antenna. The sample is placed on a translation-rotation stage to achieve a parallel scan mode for CT, and the transmitted THz signal is detected by a linearly chirped optical probe beam. The cross-section is then reconstructed by using a conventional filtered back projection (FBP) algorithm, and the 3D image is created by stacking the slices sequentially.

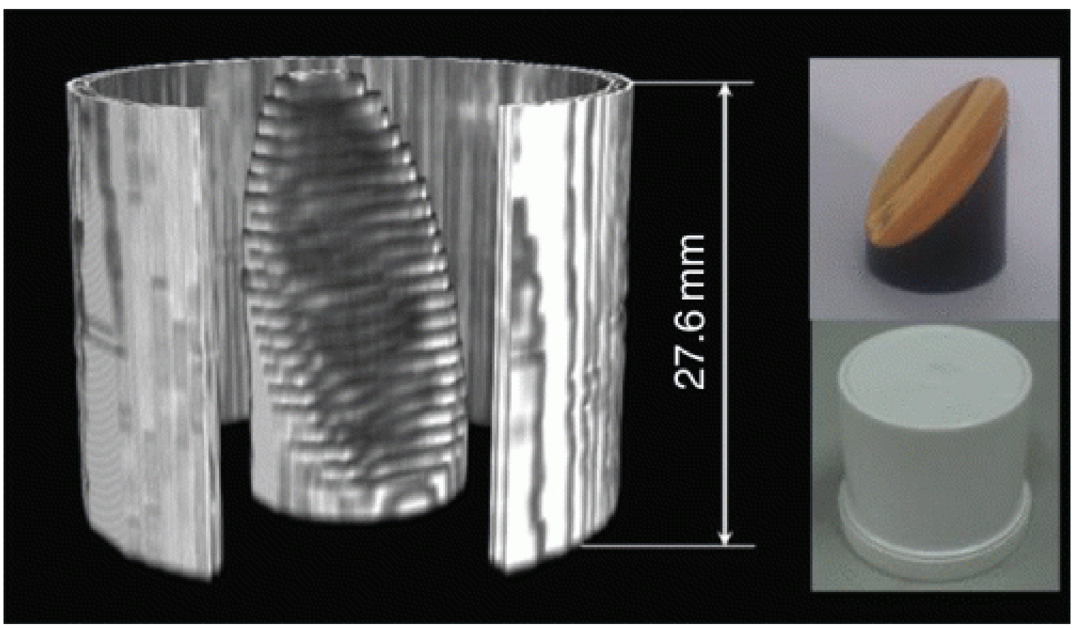
## Low-power phase

For 3D THz imaging, the TDS technique is widely used and could provide information about the phase and amplitude of the signal from a single detection, as well as a high signal-to-noise ratio. Due to the relatively low output power of THz radiation, the reconstruction work is generally based on phase information, which corresponds to the refractive index of the material.

For the THz region, the FBP algorithm is the most commonly used for image reconstruction as it has the advantages of simple hardware requirements and high accuracy. However, it suffers from several disadvantages such as beam hardening, noise sensitivity, image aberration, and a long data acquisition time.

## Rayleigh length

Although most THz applications are based on the TDS technique, there remain problems to be solved. TDS demands a complicated and sophisticated system design and imaging reconstruction is mainly based on phase information.



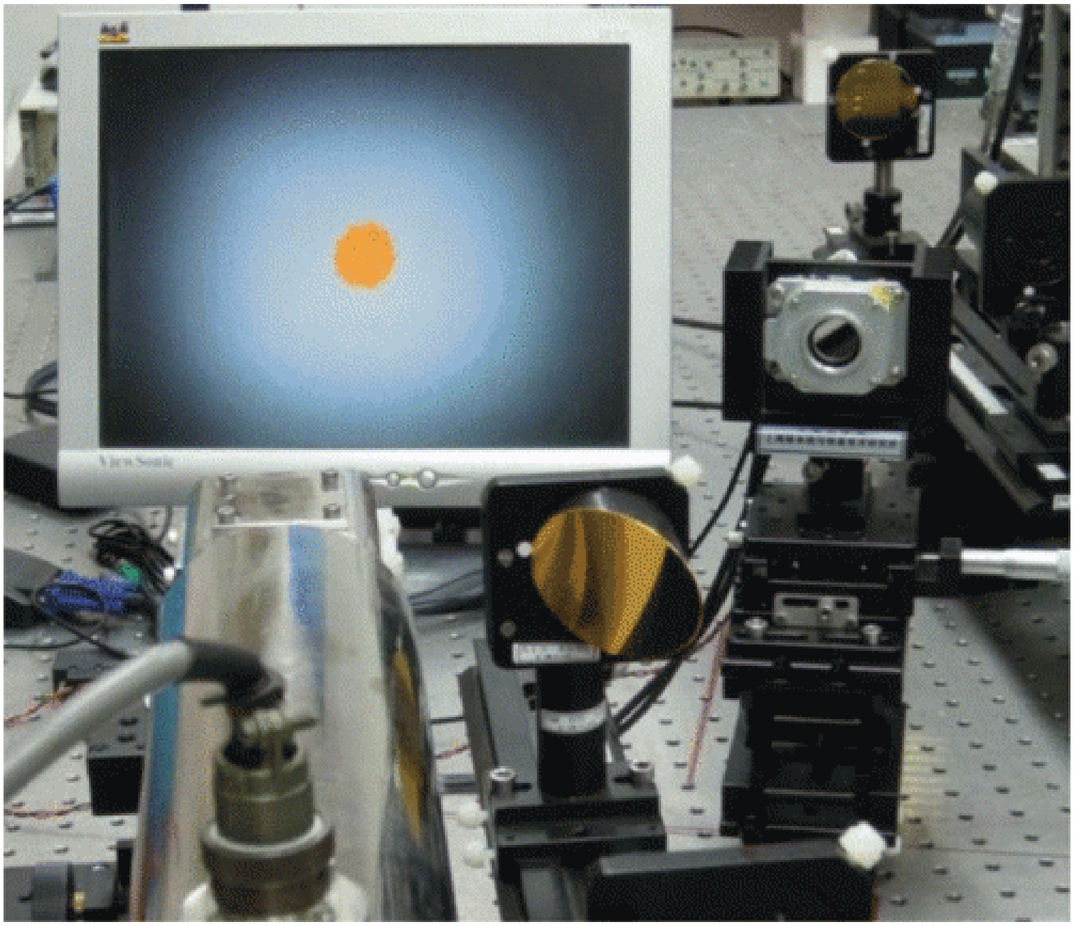

Advanced reconstruction algorithms helped the system to create accurate and clear images of hidden objects

In the experiment, to address some of these issues, Zhou told us that "a

QCL and a QWP were adopted for THz CT. The system was placed in an open environment and the image reconstruction was based on the amplitude of the THz signal in contrast to TDS." This is also in contrast to most THz CT research that uses the traditional FBP algorithm, which demands sufficient angle samplings (usually more than 36) and is very sensitive to signal noise. "Consequently," said Zhou, "we successfully used an iterative ART algorithm to prove that the iterative reconstruction methods of X-ray CT are also suitable for THz waves."

In CT, Rayleigh length plays a dominant role. The reconstruction algorithm is based on the projection data, which represents the integral of attenuation along a transmission line. "So," said Zhou "a beam with a larger Rayleigh length is a better analogue of the line pattern, which ensures the basic conditions for the algorithm to operate effectively." To further improve the case for their technique, Zhou told us that "a better spatial resolution could be realized by a short focal length, but Rayleigh length is considered to be more important in THz CT. Therefore, parabolic mirrors with long-focal length are chosen for CT imaging."

As well as advantages in processing and reconstruction, the team's system features advances in generation and detection of radiation. Traditionally, at THz frequencies, the detectors are mostly broad-band detectors, such as cryogenically cooled bolometers, which are intrinsically slow and the main responsive frequency band is located in the mid-infrared. Zhou and the team, therefore, chose a spectra-matched QWP for THz detection and rebuilt the image with equal quality.



Quantum cascade lasers are an effective source of THz radiation

## Raising the bar

The QCL/QWP based approach, combined with the ART algorithm, has been used before, but previous applications were for frequencies far below 1 THz. The images the group obtained proves that the amplitude-based reconstruction method does work very effectively in the THz band, which decreases the necessary sampling and facilitates image reconstruction.

However, Zhou said, there are still a number of challenges ahead: "most works choose point-scan mode for which the imaging speed is limited, and the reconstruction algorithm is borrowed from the X-ray CT, which is not completely suitable for the THz frequency band due to the inhomogeneity of the metal area."

## A better source

The Chinese team are already working on these problems, as Zhou explained: "recently, we used a line-focus mirror and a THz array detector to improve the data acquisition and speed; for the reconstruction algorithms, we are trying to understand the inhomogeneous effect caused by reflection – reflection invalidates the assumptions of the algorithm and some modifications should be made and this is a complicated mathematic issue."

The group are also aiming to produce high quality THz sources and detectors by improving the quality and implementation of the QCL and QWP. Significantly, their work based on these devices very strongly indicates their potential in the CT/3D imaging field.

THz CT is a natural extension of X-ray CT, which is already a powerful technique in the imaging field. "For the next decade," said Zhou, "this technique will become faster (real-time), more accurate (high resolution) and simpler (low complexity of system, room temperature operation). As these demands are met, I look forward to seeing the technique applied in biomedical and industry fields, just as X-ray CT."

**More information:** "Three-dimensional imaging with terahertz quantum cascade laser and quantum well photodetector." *Electronics Letters*, Volume 51, Issue 1, 08 January 2015, p. 85 – 86 DOI: 10.1049/el.2014.3873

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