Optics in 2024

Real-Time Hyperspectral Terahertz Imaging

RESEARCHERS

Xurong Li, **Deniz Mengu**, **Deniz Turan**, **Aydogan Ozcan** and **Mona Jarrahi** (mjarrahi@ee.ucla.edu), University of California, Los Angeles, USA

Nezih T. Yardimci, University of California, Los Angeles, USA and Lookin, Inc., USA

Ali Charkhesht, Lookin, Inc., USA

REFERENCES

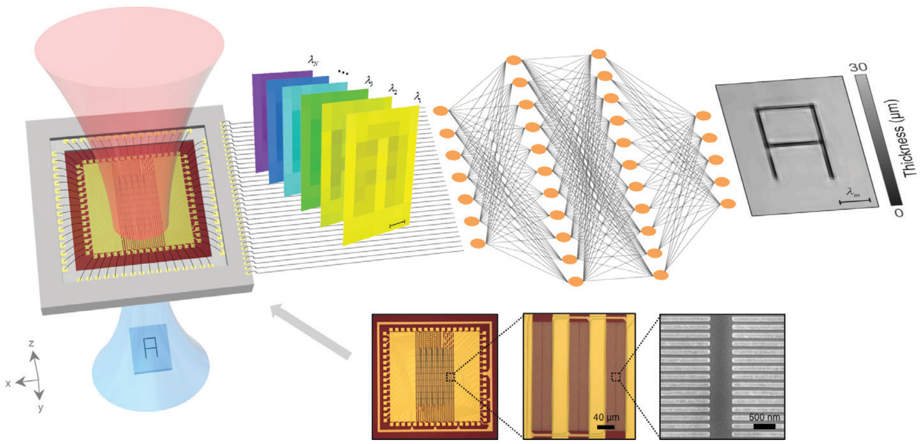
1. X. Li et al. Light Sci. Appl. **12**, 233 (2023).
2. X. Li et al. Nat. Photonics **18**, 139 (2024).
3. R.I. Stantchev et al. Nat. Commun. **11**, 2535 (2020).

Terahertz waves offer unique functionalities for remote sensing, security screening, biomedical imaging, cultural-heritage conservation and industrial quality control because many optically opaque materials are more transparent and possess distinct spectral signatures in the terahertz frequency range.[1] Among imaging modalities, terahertz time-domain imaging provides some of the most comprehensive information on the hyperspectral, ultrafast temporal, phase and amplitude characteristics of imaged objects. However, the lack of hyperspectral terahertz focal-plane arrays has restricted existing terahertz time-domain imaging systems to mainly single-pixel architectures that require raster scanning, which severely limits the imaging speed and impedes broader adoption in real-world applications.

In recent work, we have overcome these limitations with a plasmonic photoconductive terahertz focal-plane array that enables capturing the spatial, hyperspectral, ultrafast temporal, phase and amplitude information of imaged objects simultaneously.[2] The focal-plane array consists of roughly 300,000 plasmonic nanoantennas, which serve as both optical and terahertz beam concentrators. They provide a high spatial overlap between the optical and terahertz radiation inside nanoscale photoconductive active regions for efficient terahertz detection. The collective response of the nanoantennas is electronically read, providing more than 60-dB dynamic range and 3-THz bandwidth across all imaging pixels in 164 μs—demonstrating an imaging speed a thousand times faster than state-of-the-art multi-pixel terahertz imaging systems[3] and enabling the first hyperspectral terahertz video captured at 16 frames per second.

To showcase the features of our hyperspectral terahertz focal-plane array, we realized pixel-super-resolution imaging using a convolutional neural network trained with deep learning that harnesses the broadband spatial amplitude and phase information captured by the array. As a proof of concept, we super-resolved etched patterns in a silicon substrate and reconstructed their 2D shape and depth with more than 1,000 effective pixels, a 16-fold enhancement in resolution. The super-resolution imaging architecture was employed in both lens-free and lens-based terahertz imaging settings, and the generalization of the imaging performance was demonstrated for different types of objects.

The feasibility of real-time hyperspectral terahertz imaging could help exploit the untapped potential of terahertz waves to solve many real-world problems. As an example, we demonstrated that the hyperspectral terahertz focal-plane array offers a solution for nondestructive in-line quality control of battery electrodes during manufacturing. By extracting volumetric information about lithium-ion battery electrode coatings, we detected various types of hidden defects and structural non-idealities, which, if left undetected, could diminish the performance of batteries and create safety hazards. We believe the capabilities of our array could enable transformative advances in many other applications that use hyperspectral and 3D terahertz images of objects for industrial inspection, security screening and medical diagnosis. OPN



Plasmonic photoconductive terahertz focal-plane array captures hyperspectral, time-resolved terahertz images, and a pixel-super-resolution neural network processes these images to reconstruct a higher-resolution image.