

We3B-319-EB149

16 Frames-per-Second Terahertz Time-Domain Imaging through a Plasmonic Photoconductive Focal-Plane Array

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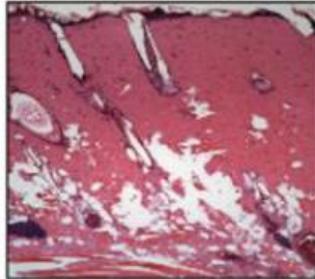
¹University of California, Los Angeles, California, USA

Terahertz Imaging

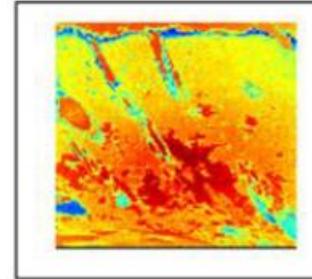


- Terahertz waves can penetrate through many optically opaque materials.
- Terahertz waves are non-ionizing and non-destructive.
- Many molecular species have unique spectral signatures in the terahertz range.

Biomedical imaging



Visible image



THz image

Art conservation



(a) Image in the visible.



(b) 50% visible, 50% THz image.



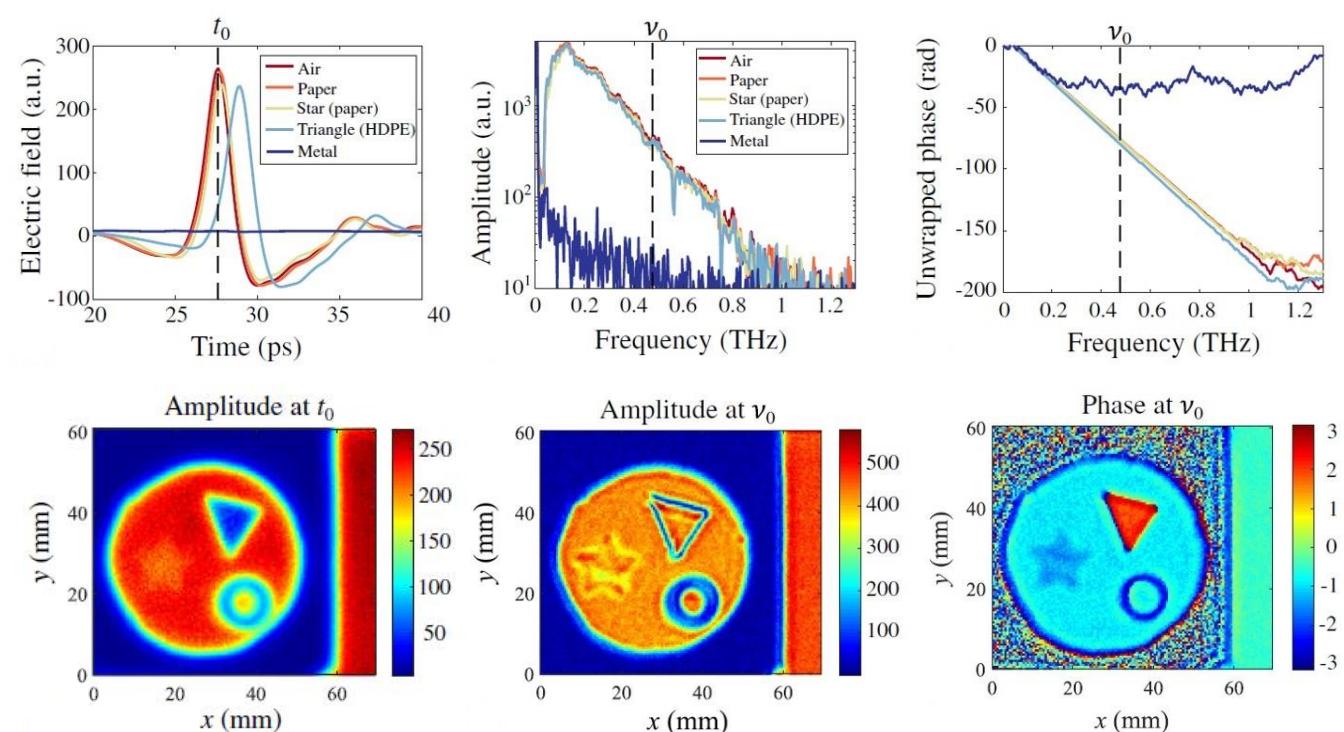
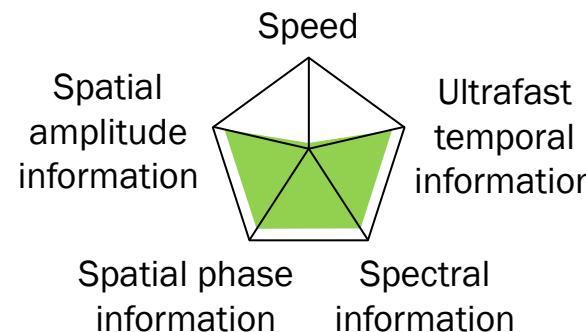
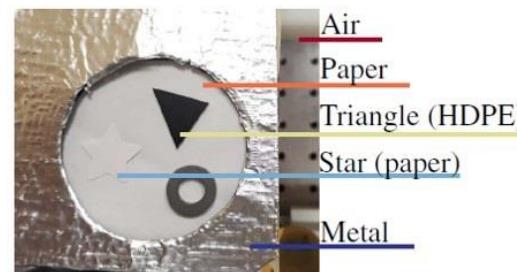
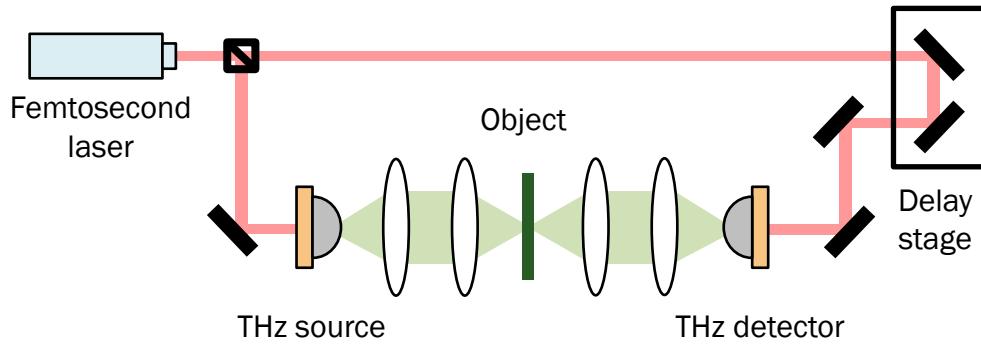
(c) 100% THz image.

Security screening



Arbab, M. H. et al. *Biomed. Opt. Express* **2**, 2339 (2011).
Seco-Martorell, C. et al. *Opt. Express* **21**, 17800 (2013).
<https://www.laserfocusworld.com>

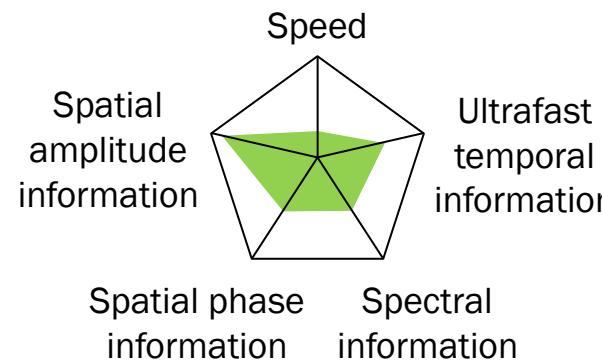
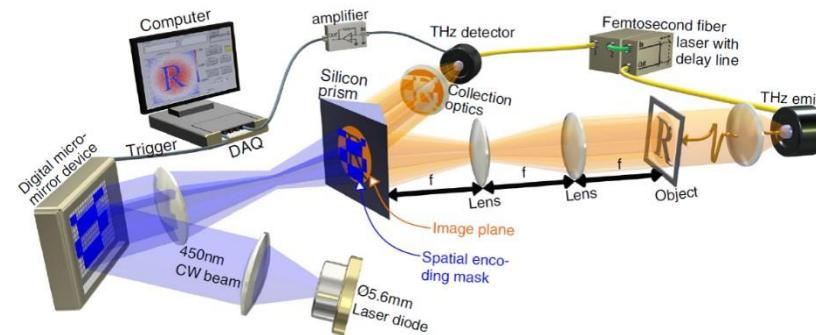
THz Time-Domain Spectroscopy (TDS) System



- Single-pixel imaging system.
- Image data are acquired by raster scanning either the object or the imaging system.

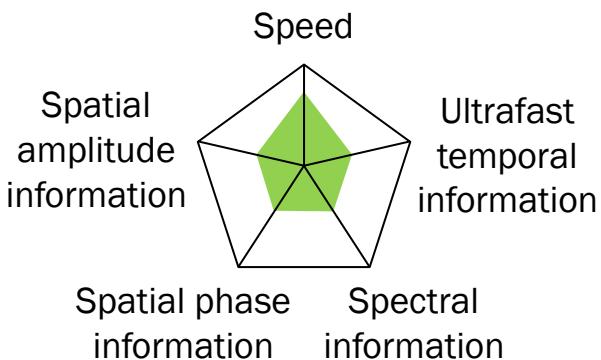
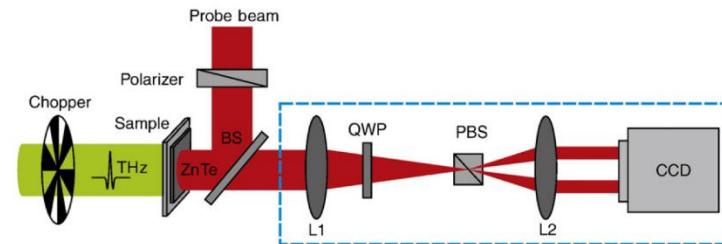
 Guerboukha, Hichem, et al. *Advances in Optics and Photonics* 10.4 (2018)

THz TDS system + Compressive sensing



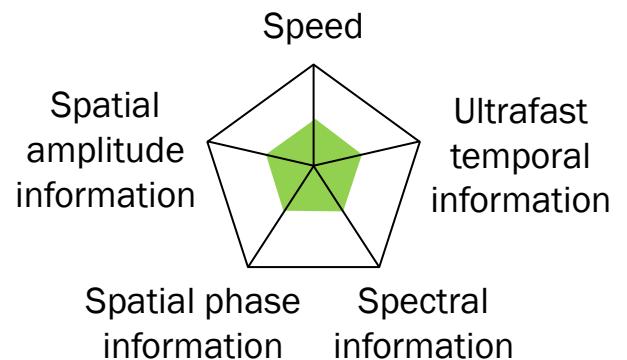
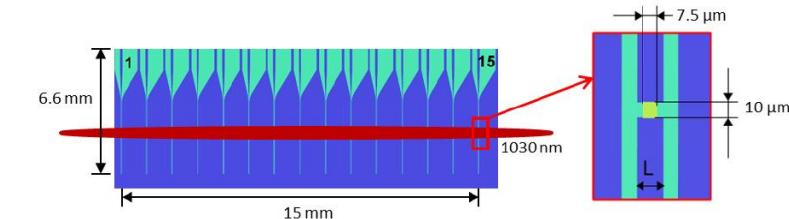
Stantchev, R. I., et al. *Nat Commun* 11, 2535 (2020).

Electro-optic THz + Optical camera

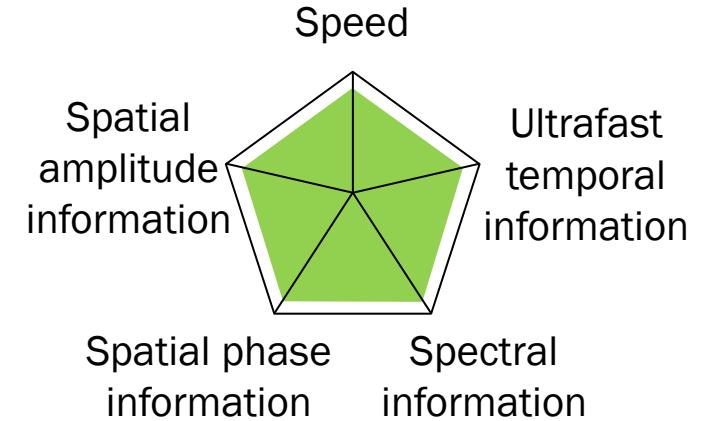
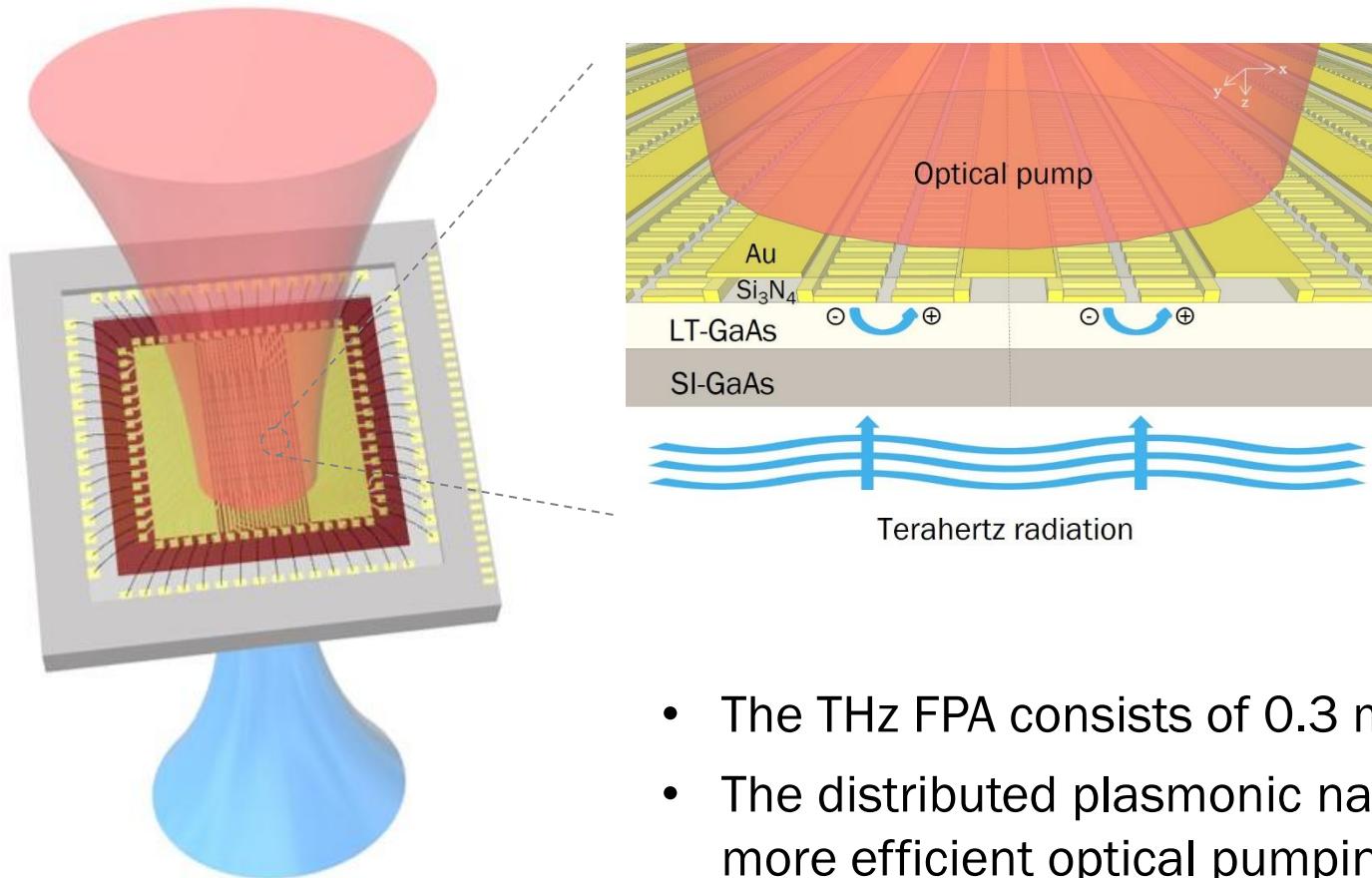


Wang, Xinke, et al. *Optics Communications* 283.23(2010)

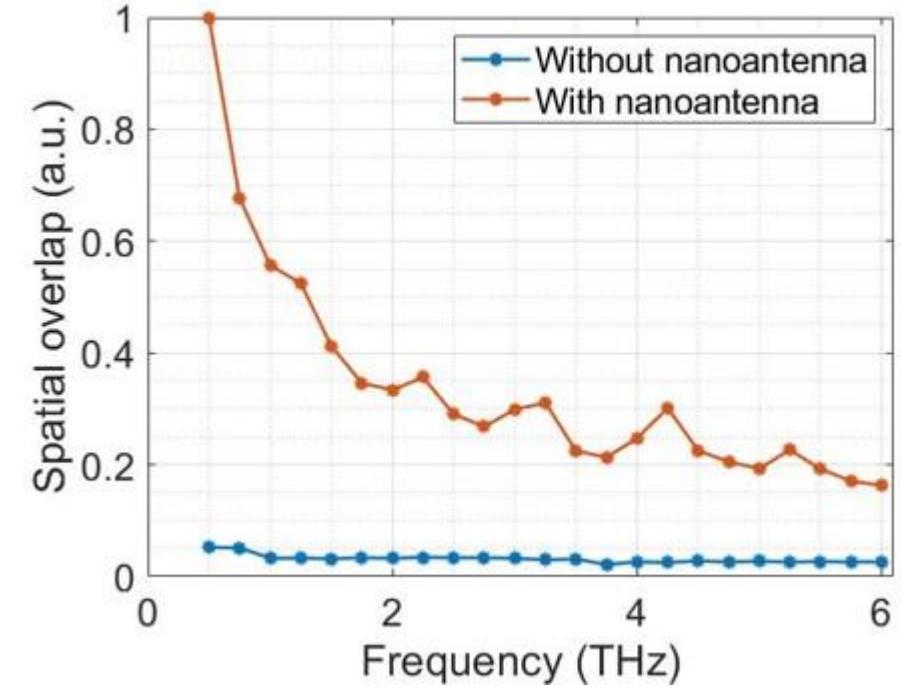
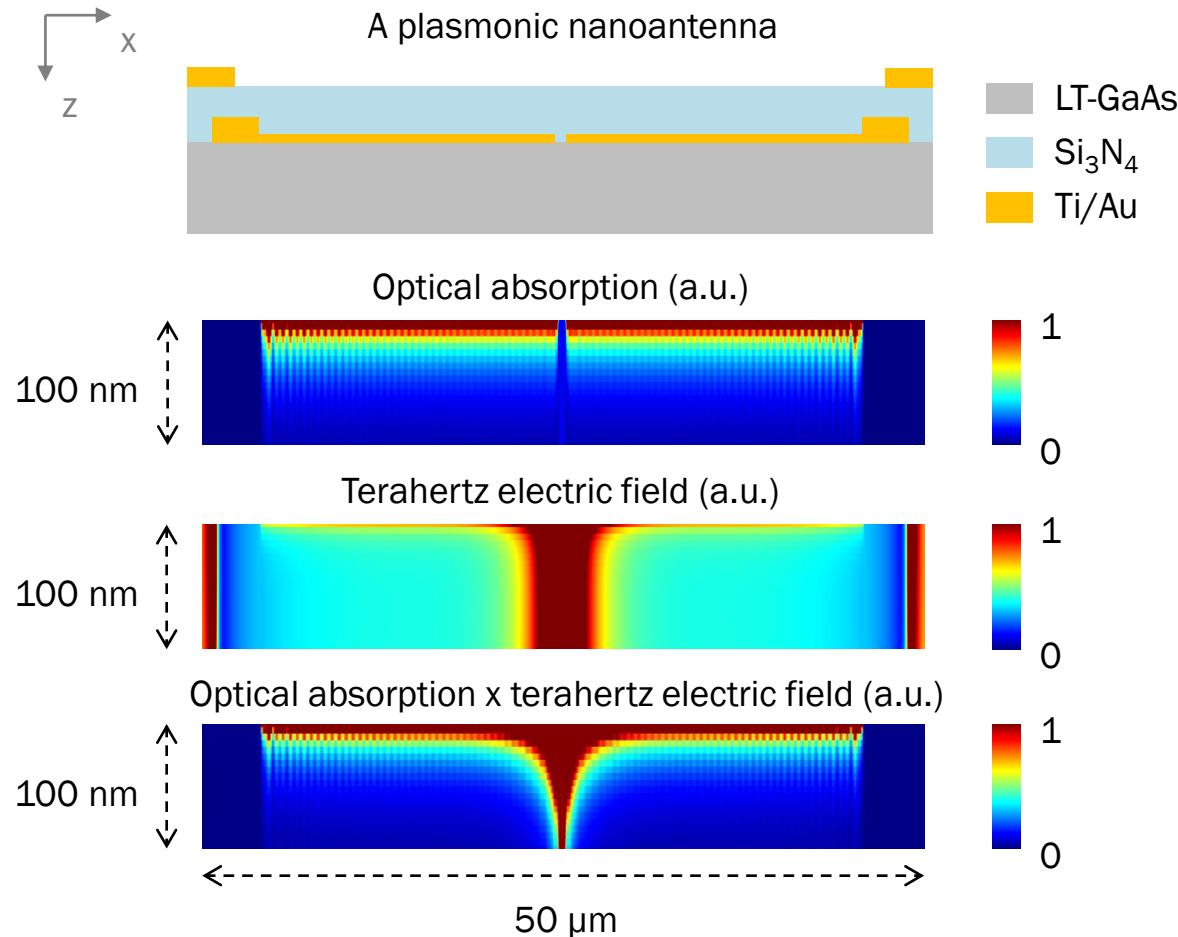
THz PCA 1D array



A. Brahm, et al. *Opt. Express* 22.11(2014)

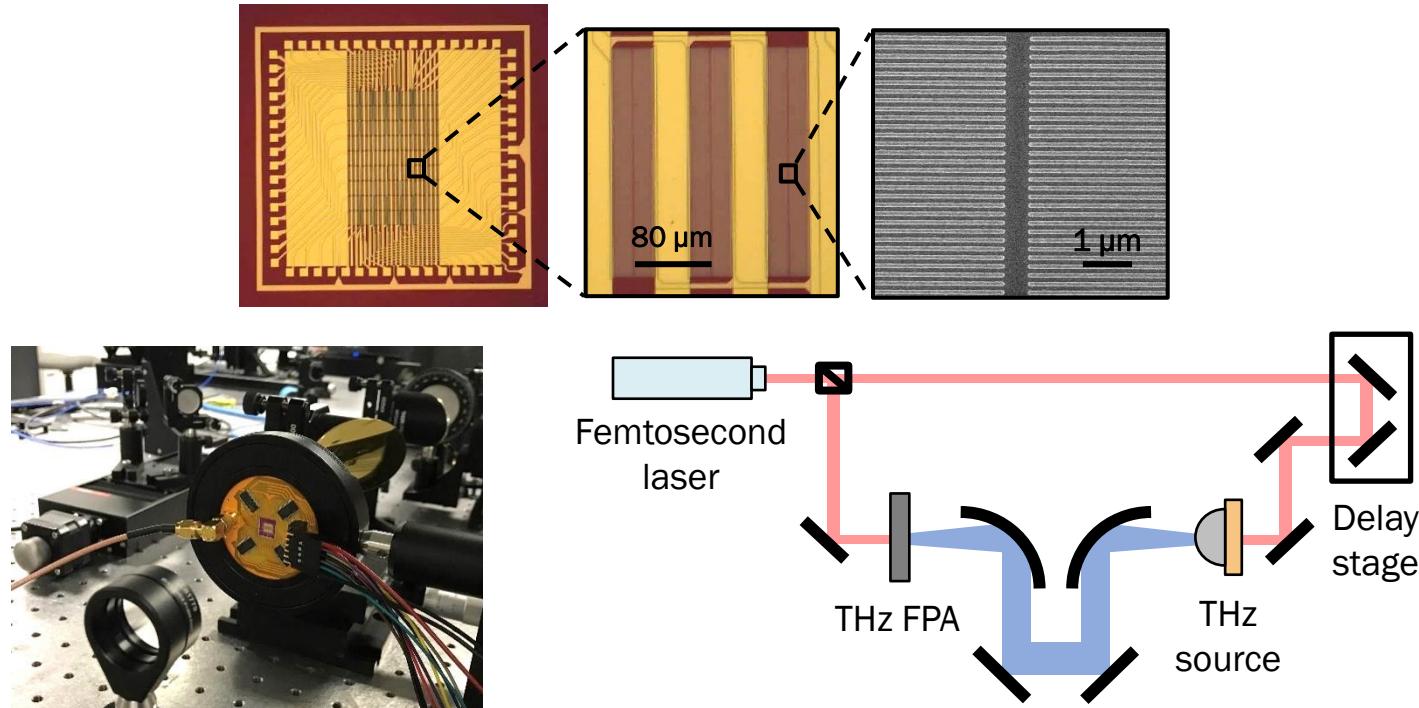


- The THz FPA consists of 0.3 million plasmonic nanoantennas.
- The distributed plasmonic nanoantenna array architecture provides more efficient optical pumping and terahertz detection.

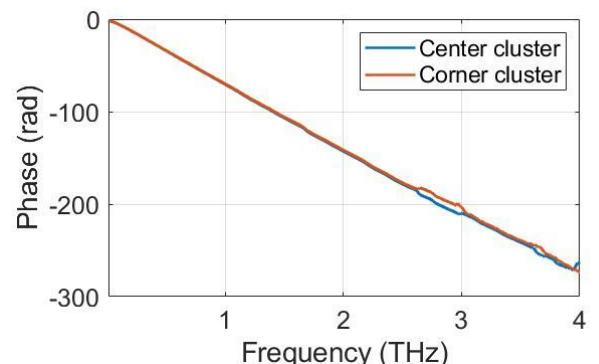
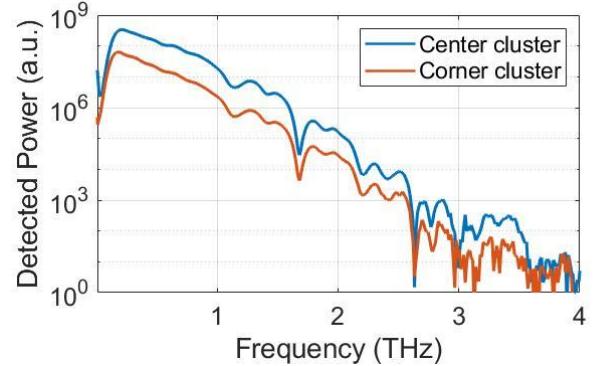
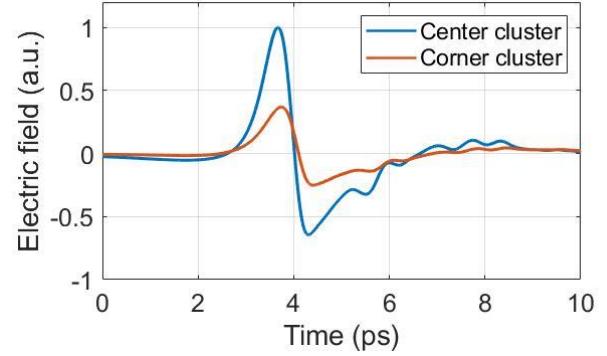


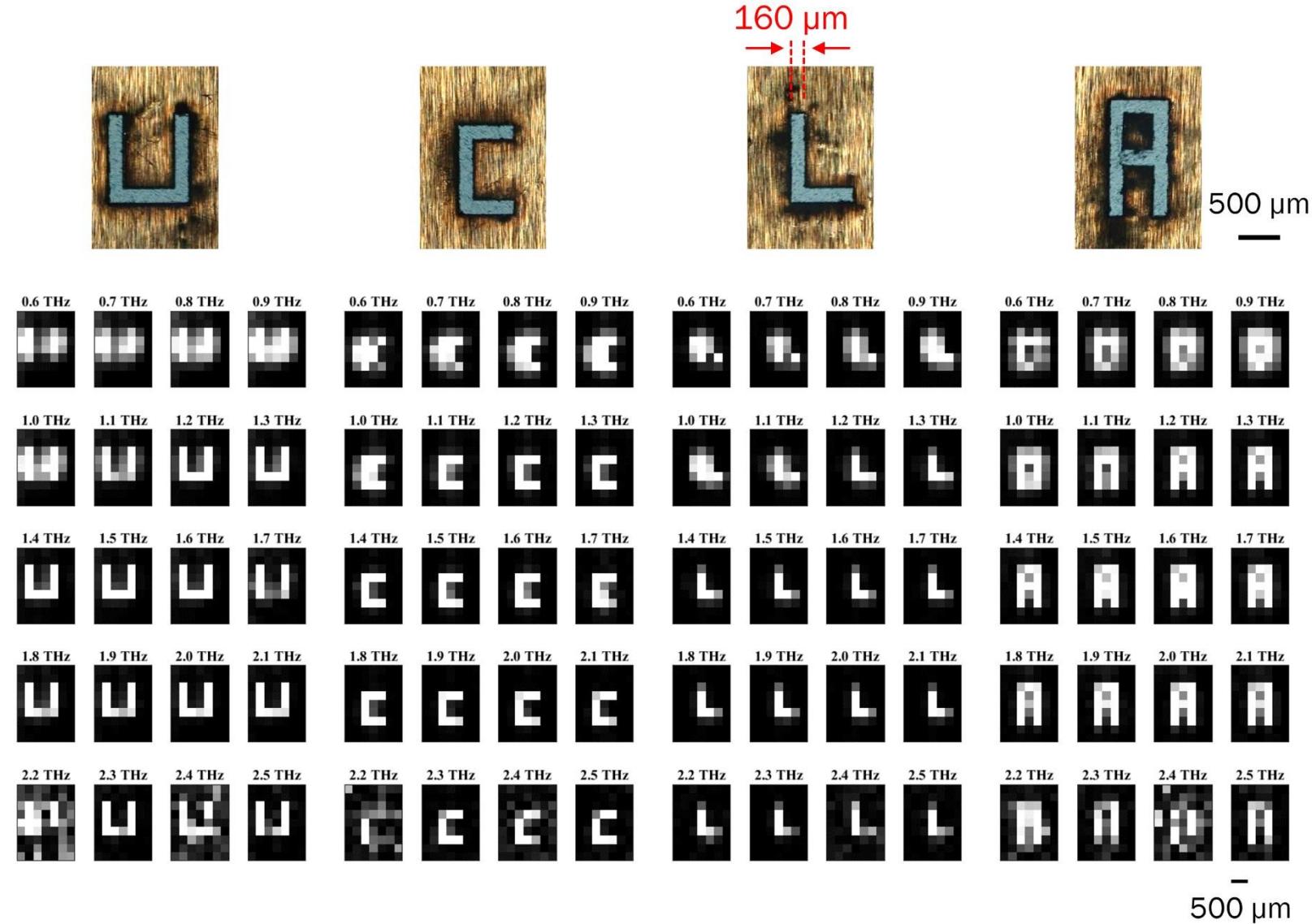
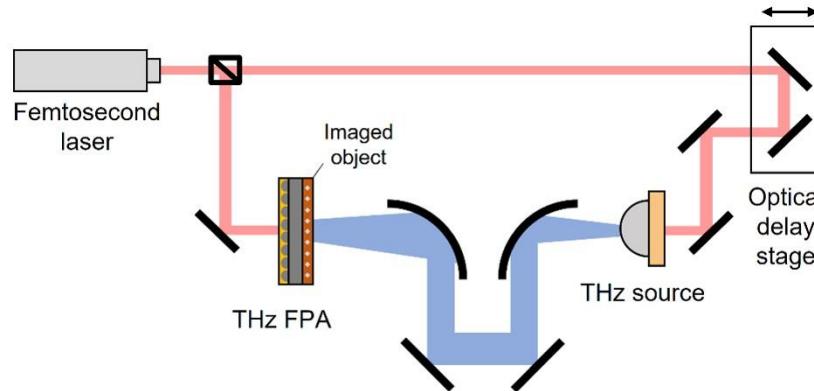
The nano-antennas are designed for a strong spatial overlap between the optical absorption and the terahertz electric field profiles.

Plasmonic Photoconductive THz FPA



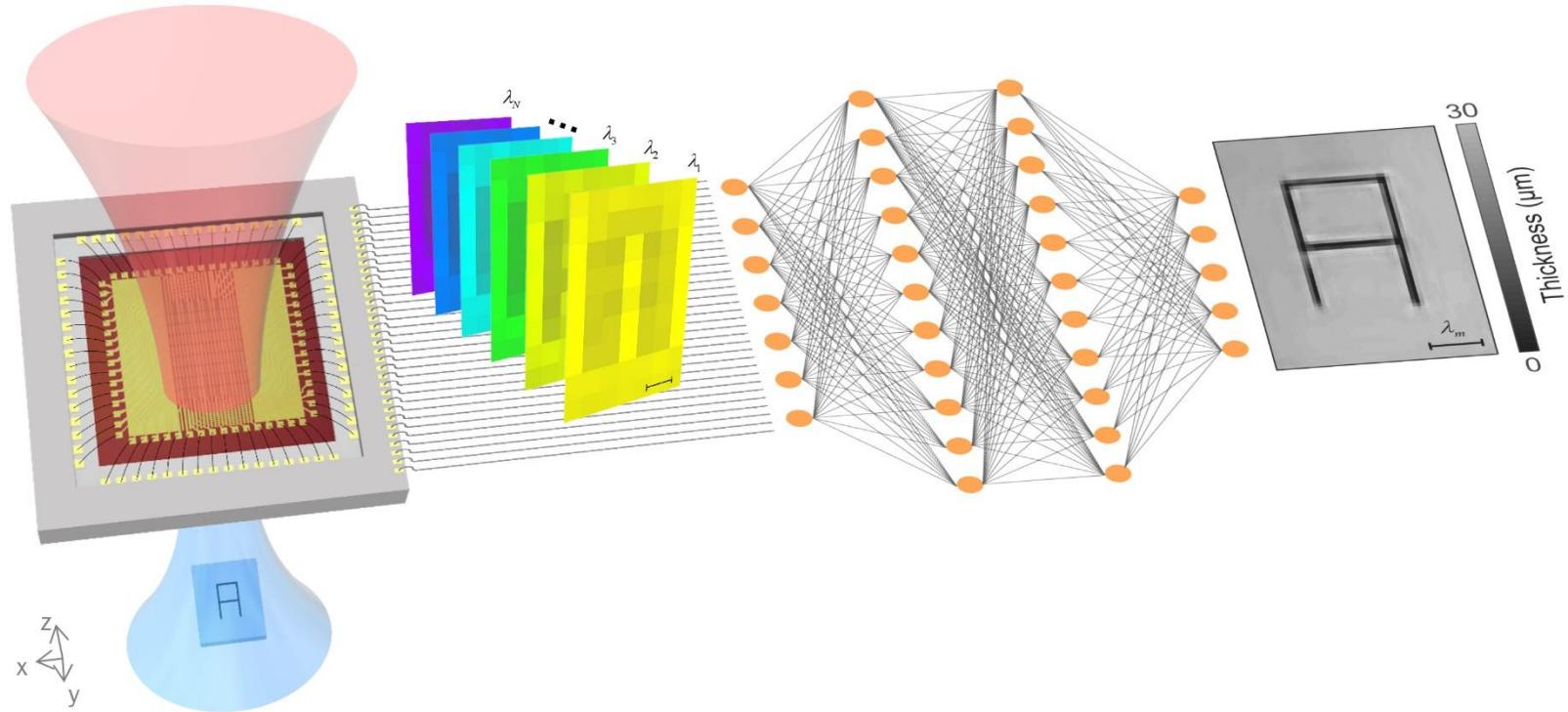
- 0.3 million plasmonic nanoantennas are grouped into 63 clusters.
- The area of each cluster is $270 \times 240 \mu\text{m}^2$.
- The total active area is $2.4 \times 1.7 \text{ mm}^2$.
- A programmable FPGA-based readout circuit is used for data acquisition.
- The optical pump power for THz FPA is 660 mW.





- Laser-milled apertures in 65 μm -thick copper tapes.
- Minimum aperture width is 160 μm .

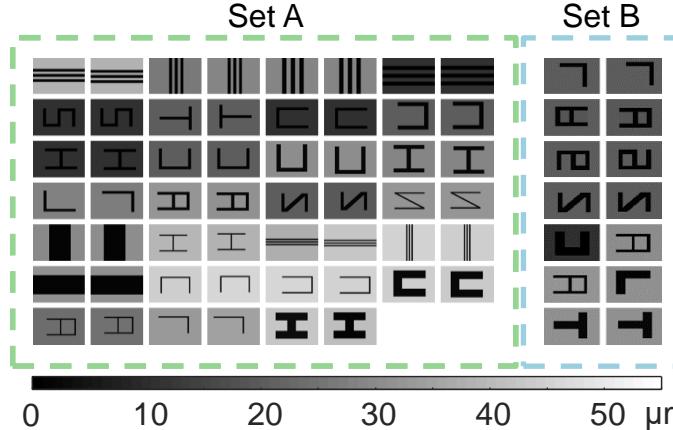
Pixel Super-Resolution (PSR) with the THz FPA



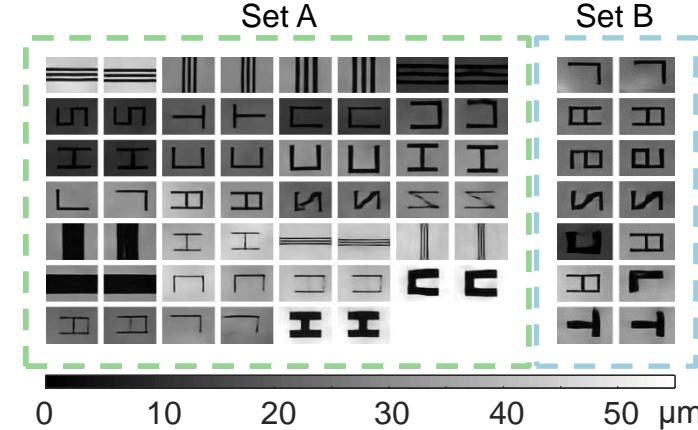
- The THz FPA captures the broadband amplitude and phase data of an etched silicon object.
- A PSR neural network reconstructs a higher resolution image with an effective pixel count of more than 1 kilo pixels and a 16-fold enhancement in the space-bandwidth product.

PSR Terahertz Imaging In Lens-Free Imaging System

Ground truth images

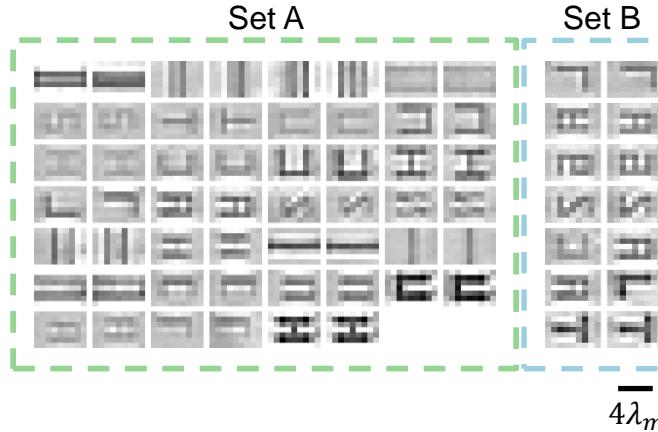


Reconstructed super-resolved images

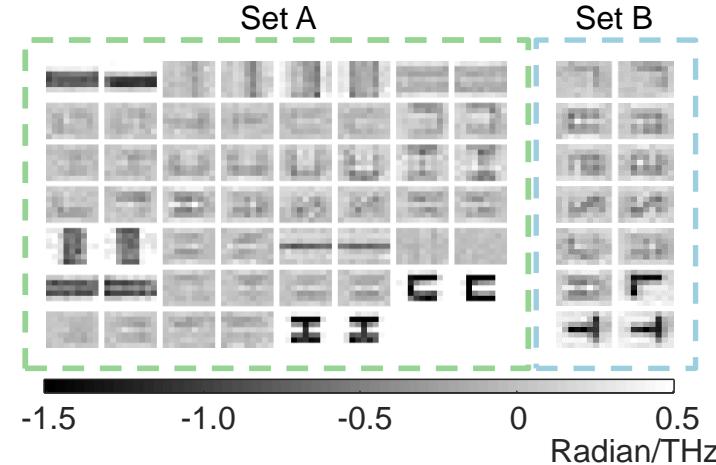


- Set A: Samples with unique depths
- Set B: Samples with unique 2D patterns and depths
- SSIM: 0.839 ± 0.098
- PSNR: $16.60 \pm 3.67 \text{ dB}$

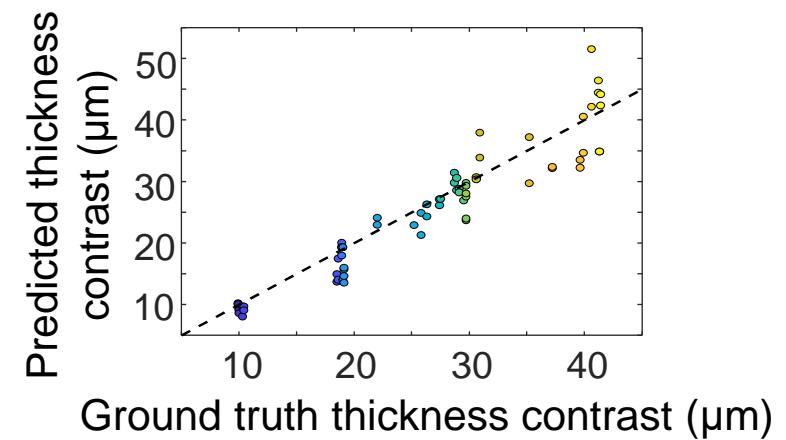
Amplitude images @ λ_m (0.754 THz)



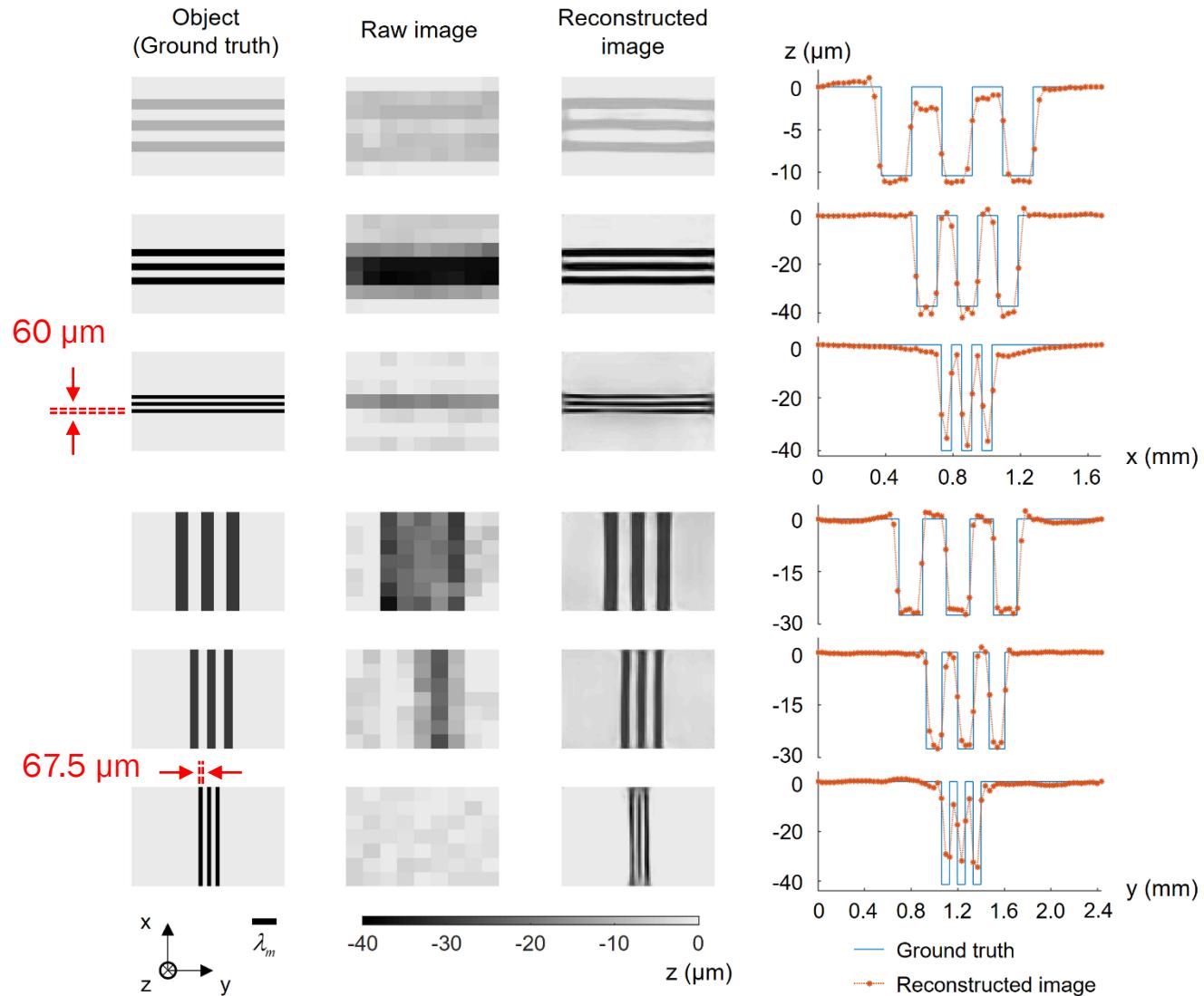
Relative spectral phase slope



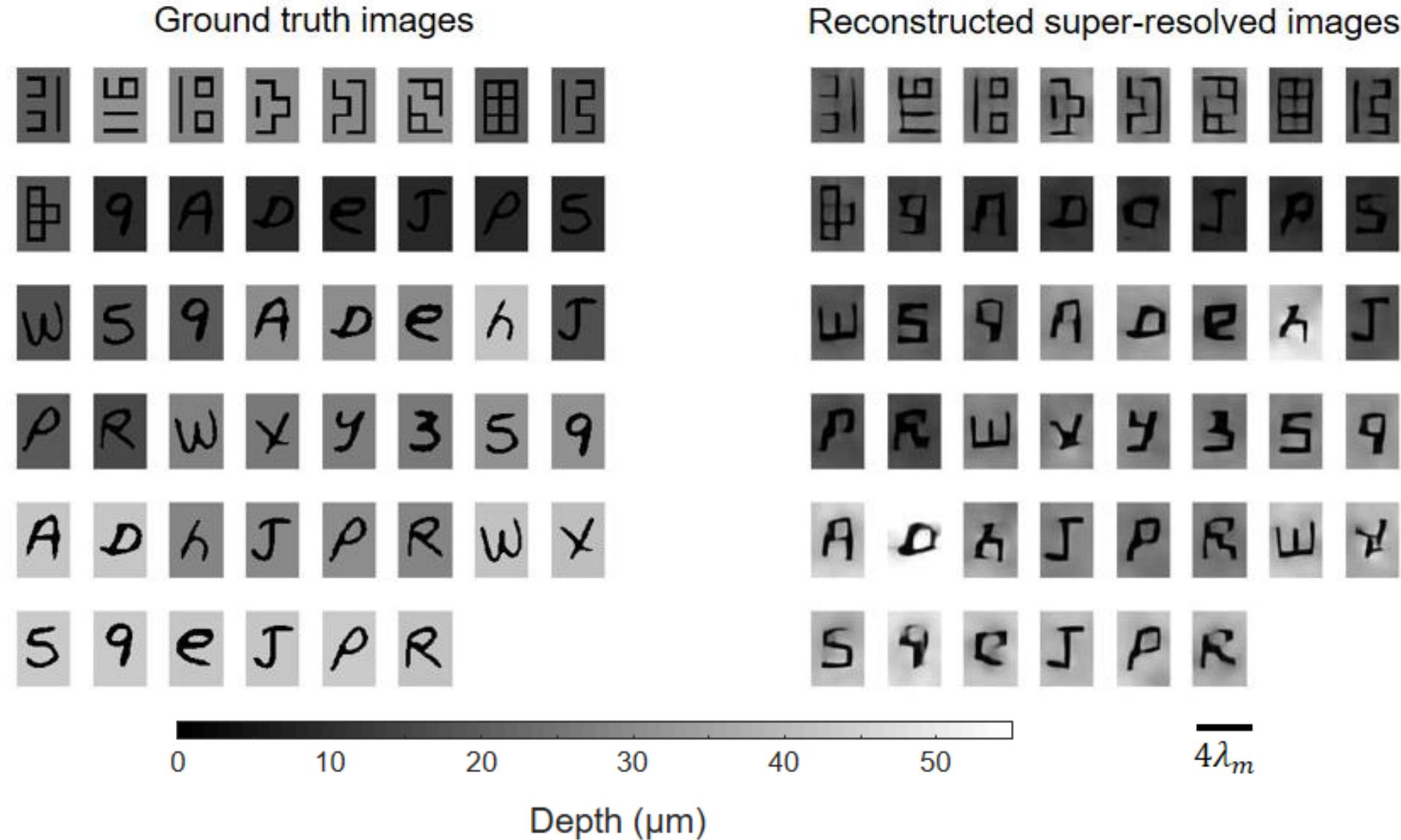
Thickness contrast prediction accuracy

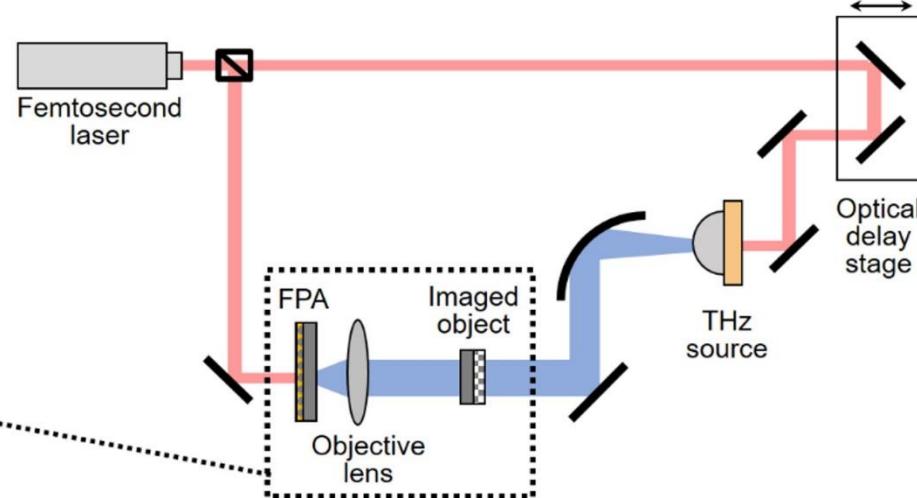
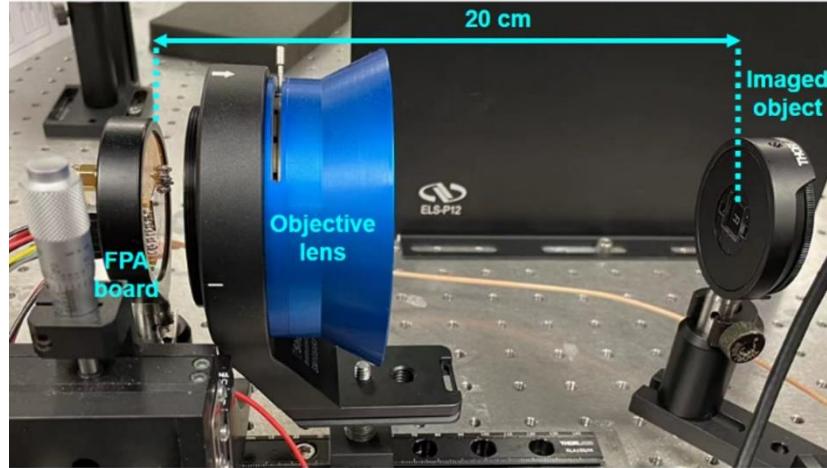


PSR Terahertz Imaging Resolution Quantification

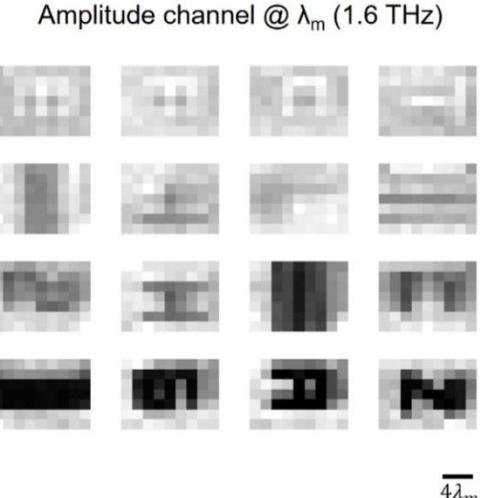
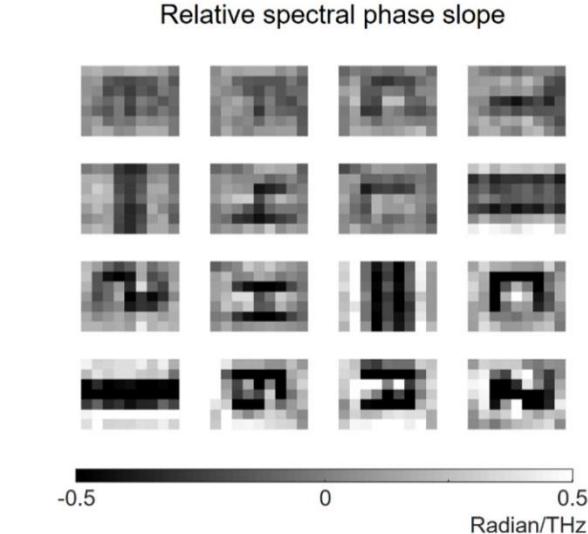
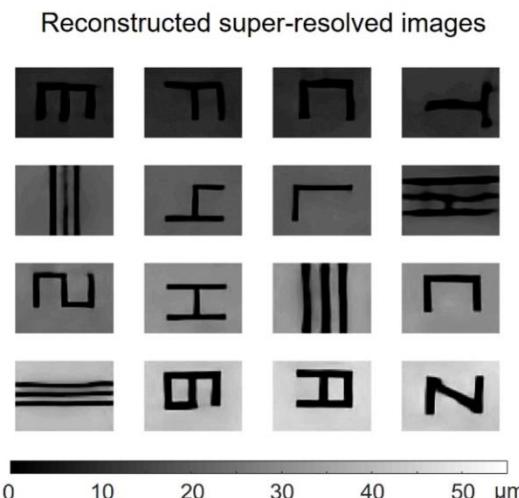
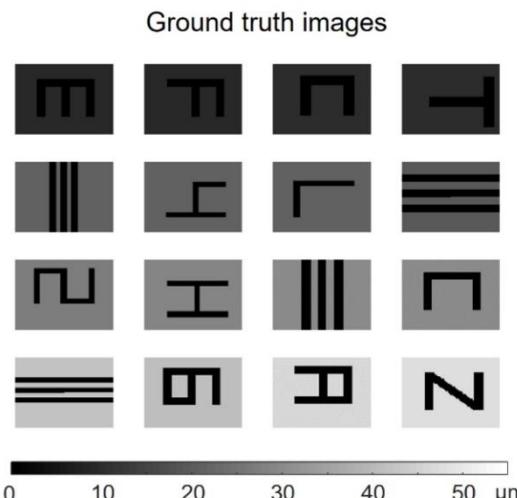


- The linewidths and separations are $0.75\times$, $0.5\times$, and $0.25\times$ of the FPA pixel size in both the horizontal and vertical directions.
- The PSR-enhanced THz FPA can provide $4\times$ resolution enhancement in both the horizontal and vertical directions.



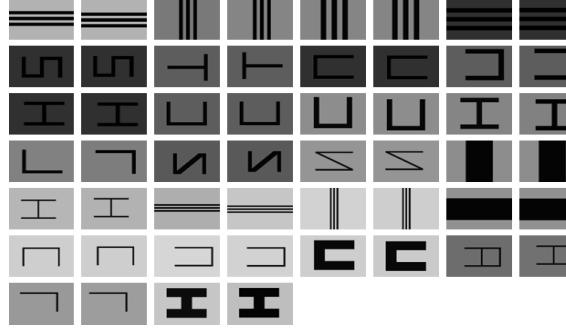


- SSIM: 0.78
- PSNR: 14.5 dB

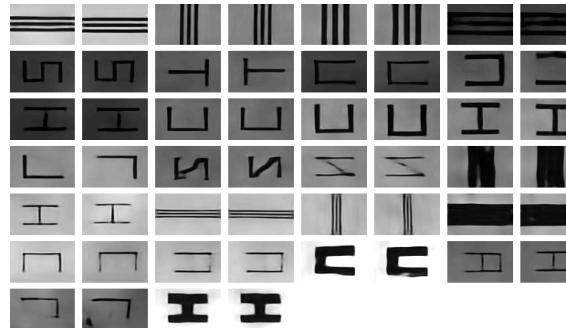


PSR THz Imaging Speed Analysis

Ground truth images

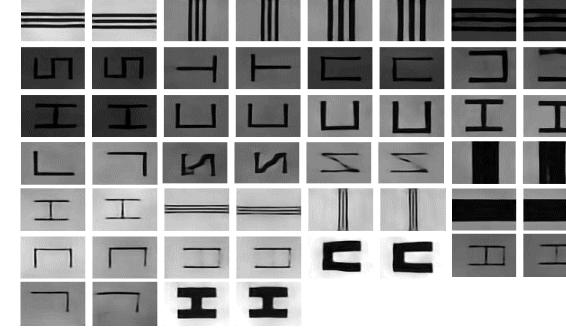


Reconstructed images
@ 0.004 fps

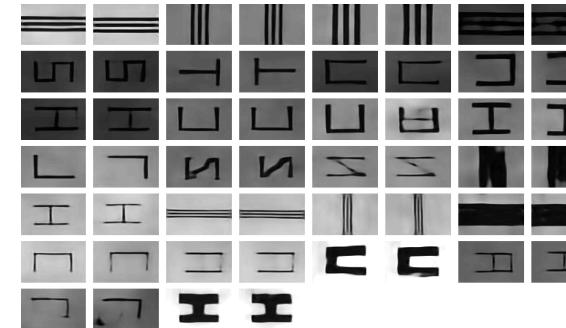


Reconstructed images

@ 0.004 fps



Reconstructed images
@ 3.11 fps



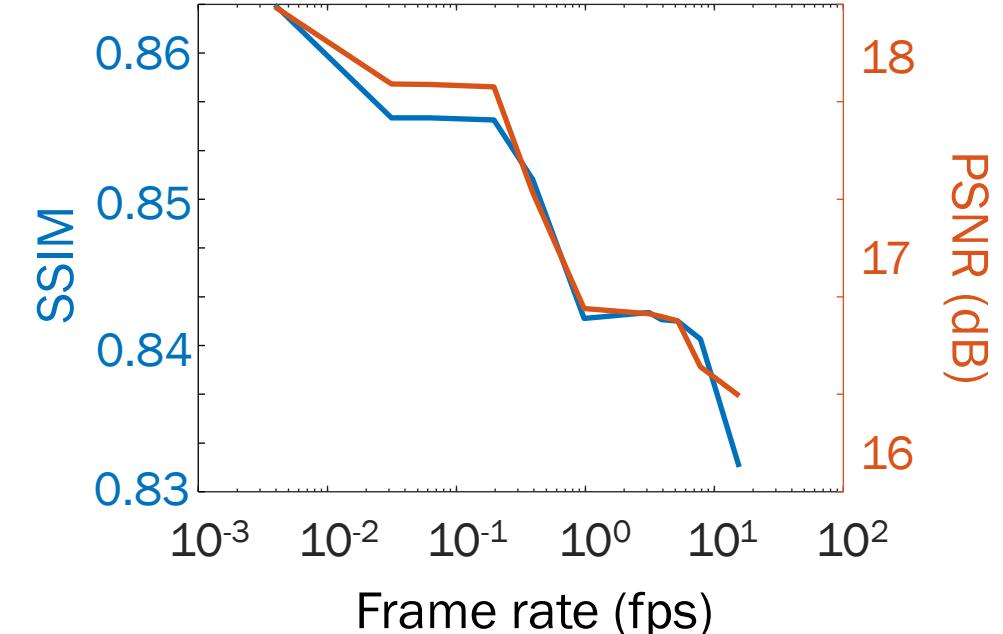
Reduce the delay stage range

0.004 fps



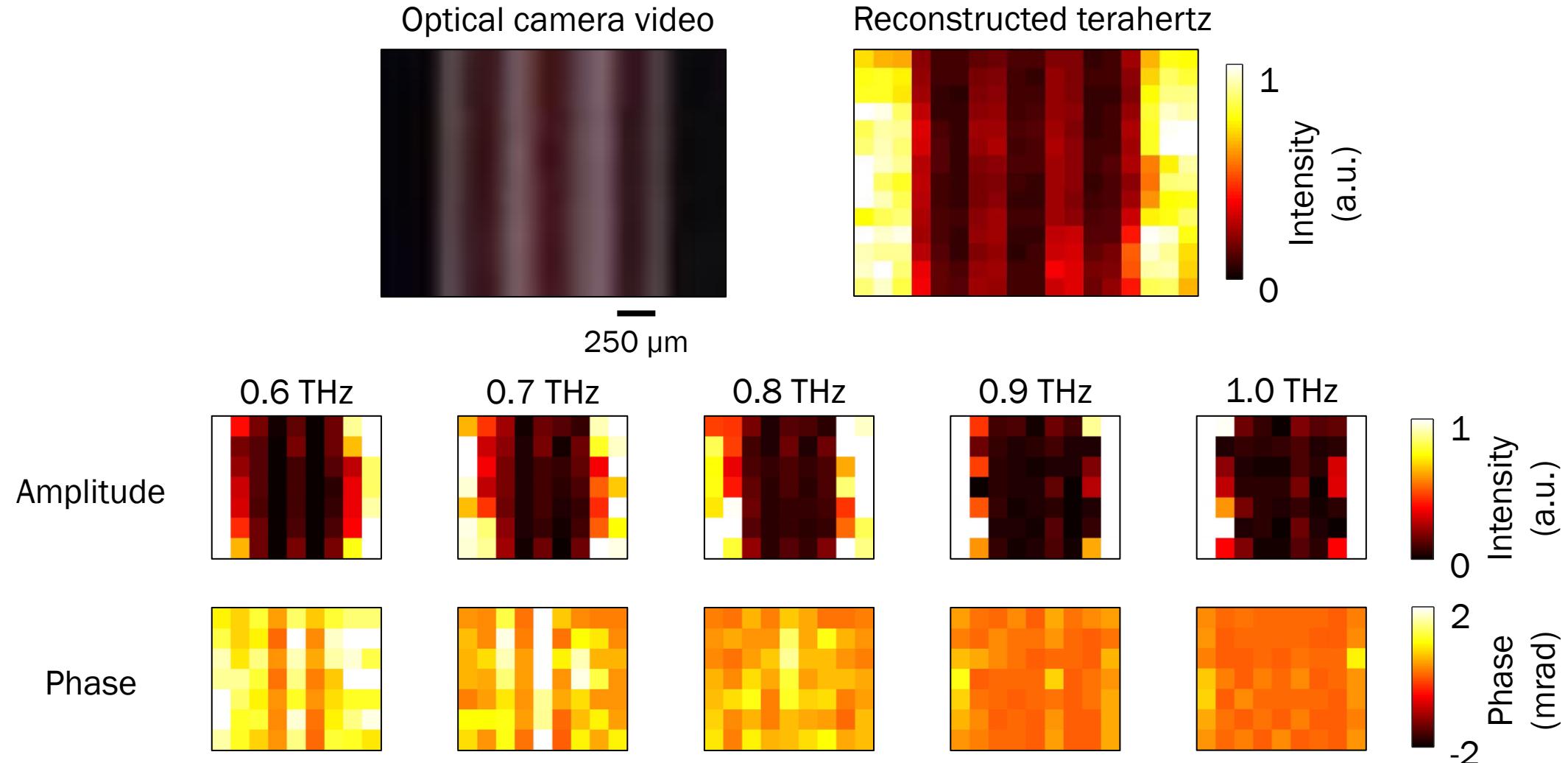
Increase the delay stage speed

Use single trace

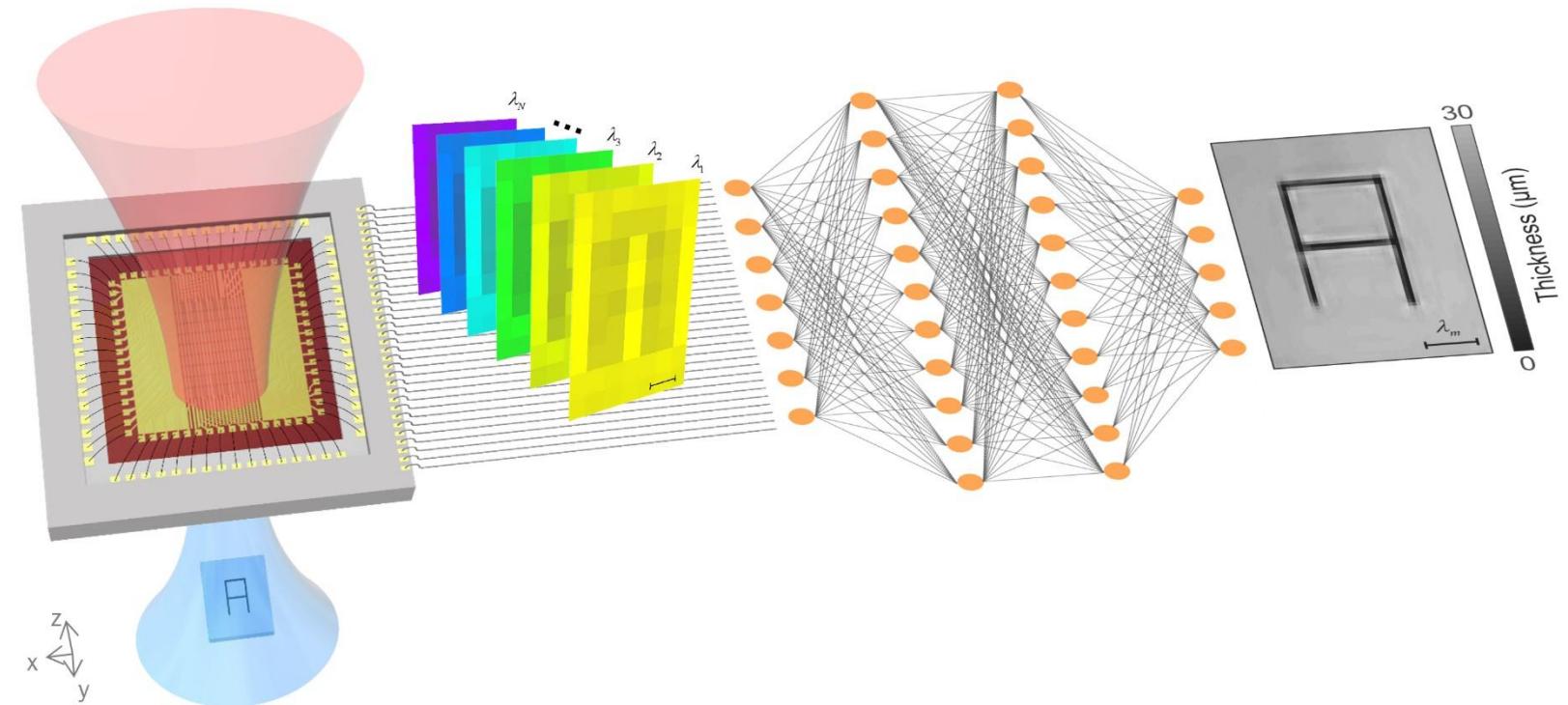
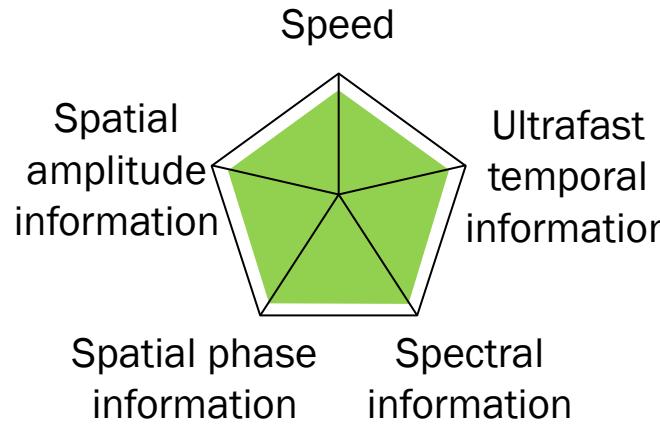


A Super-Resolved THz Video

Video frame rate: 16 fps



Summary



- The THz FPA can simultaneously provide the spatial amplitude and phase information, ultrafast temporal and spectral information of an imaged object with a high imaging throughput.
- A PSR neural network can reconstruct a higher resolution image with an effective pixel count of more than 1 kilo pixels and a 16-fold enhancement in the space-bandwidth product.
- The first terahertz time-domain video of a flowing water in plastic pipes at 16 fps.

Thank you!



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