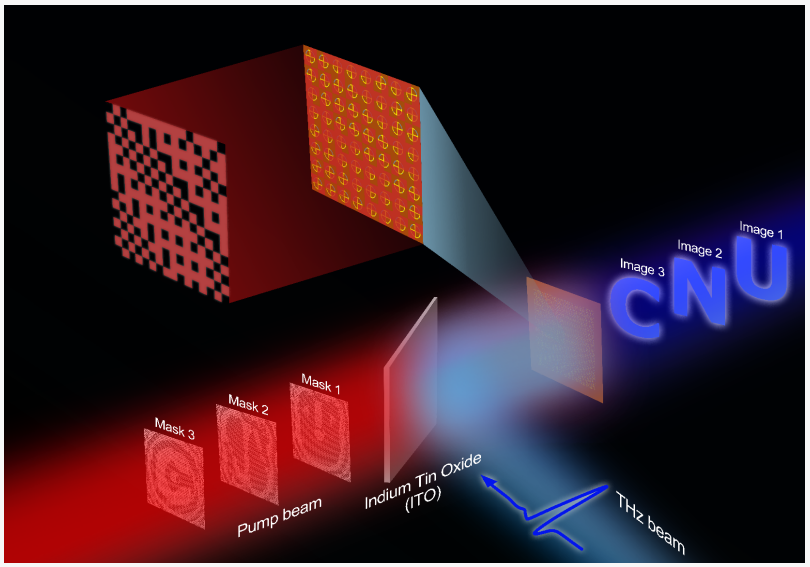
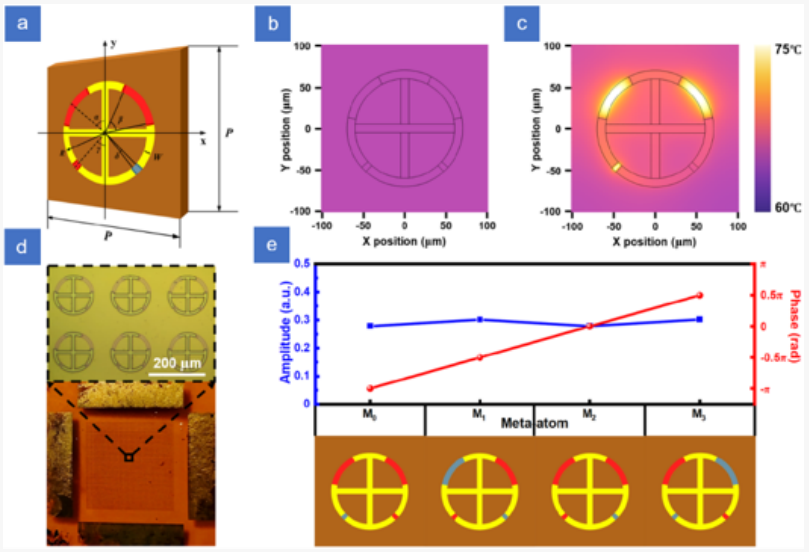
Pixel-controlled programmable metasurface as phase-type spatial terahertz modulator

SHANNON, CLARE, IRELAND, September 14, 2026 / EINPresswire.com/ -- A pixel-controlled programmable metasurface capable of dynamically reshaping terahertz (THz) waves could open new possibilities for compact imaging, communications and optical systems. The device functions as a phase-type spatial terahertz modulator, combining independent pixel-level encoding with the ability to switch between multiple optical functions on a single platform.



Schematic of the pixel-controlled programmable metasurface as a PSTM.



Design of the meta-atom in the programmable metasurface.

Terahertz radiation occupies the electromagnetic spectrum between infrared and microwaves and offers properties including high resolution, non-ionizing operation and substantial channel capacity. These characteristics make THz technology attractive for applications ranging from material characterization and sensing to high-capacity wireless communications. However, creating compact devices that can flexibly manipulate THz wavefronts remains challenging.

The new approach uses a 50 × 50 pixel array of specially designed meta-atoms incorporating vanadium dioxide (VO□), a phase-change material. Each meta-atom contains four VO□ patches embedded within a metallic split-ring resonator. Patterned femtosecond laser pulses selectively activate these patches, allowing the phase response of

individual pixels to be programmed. A flexible polyimide substrate helps localize the photo-induced heating and suppress thermal crosstalk between neighboring elements.

At an operating frequency of 0.7 THz, the platform employs 2-bit encoding with four programmable states spanning a full 2π phase range in approximately π/2 increments. The experimentally measured amplitude conversion efficiency reaches 27%, demonstrating practical polarization conversion alongside programmable phase control.

Importantly, one metasurface can perform several distinct functions simply by changing the spatial pattern of the optical pump. Demonstrations include a dynamic zoom meta-lens with switchable focal lengths of 10 and 12 mm, a focused vortex-beam generator with tunable topological charges of +1 and −1, and dynamic holographic imaging. The holographic capability was demonstrated by reconstructing and switching between the letters “C”, “N” and “U”.

By combining pixel-level programmability, phase control and multifunctionality in a compact transmissive architecture, the platform provides a route toward increasingly integrated THz components. Further improvements in response speed, efficiency and optical pattern switching could strengthen its prospects for next-generation wireless communication, high-resolution imaging and reconfigurable terahertz systems.

Keywords: metasurface, phase change material, programmable, phase-type modulator, pixel-level encoding
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ISSN: 2096-4579
CN: 51-1781/TN

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Li GB, Li GY, He ZH et al. Pixel-controlled programmable metasurface as phase-type spatial terahertz modulator. Opto-Electron Adv, 260028 (2026). DOI: 10.29026/oea.2026.260028

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