# Terahertz metasurface platform for modulation, holography, and encryption

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Dynamic control of terahertz (THz) waves is a hot topic and has been the object of intense research for the myriads of applications that are enabled in this frequency range, such as wireless communications, spectroscopy, sensing, and biomedical imaging.[1,2] Steering and modulating THz waves has been achieved with a plethora of designs and architectures, from all-electronic to optically controlled, with temperature or mechanical tuning by using a variety of active elements, ranging from semiconductors to bidimensional and phase changing materials. Among the many methodologies developed in the recent years, the metamaterial route emerges as the most promising solution to obtain THz modulation, thanks to its unique integration and miniaturization capability, versatility, and efficiency.[3]

The recent publication from Zhou et al.[4] inserts itself in this fast-evolving and extremely competitive field with an innovative approach. The authors demonstrated a selective, dual-mode modulation of THz waves by optical pumping at silicon pillar array metasurfaces. The polarization modulation capability was achieved by an ingenious photonic engineering of the modes supported by the pillar distribution, and by their pump wavelength dependence. The spatial overlap, between wavefunctions for some supported modes and the pump-induced changes, was designed to be critically dependent on the pump-laser excitation. It is worth highlighting that polarization modulation and active tuning of the light helicity are among the most elusive and complex functionalities to be exploited. It is also rare to find a unique platform capable of addressing more than a single functionality at the time.

As schematically depicted in Fig. 1, this approach can be used to encode multiple states in the output polarization, thus moving beyond standard modulation techniques. Beyond this advance, the authors exploited the anisotropy between resonant modes as well as the pump wavelength dependence to realize a more complex metasurface yielding intriguing photonics scenarios such as holographic imaging. Encoding phase information in THz imaging for 3D image reconstruction has gained vast popularity for digital twin, 3D medical imaging, and tomographic applications.[5,6] Classical holography is based on the interference between a THz illuminating waveform and a second reading beam.[7] In Ref. 4, Zhou et al. proposed a proof-of-concept arrangement, where the phase information is encoded directly in the pattern distribution. The encrypted holographic image in the THz wavefront appears only in specific pumping wavelength/fluence ranges. Accordingly, these results offer an unconventional perspective in fields such as cryptography, authentication, and secure communications.[8,9] The cryptographic key would be embedded in the optical token to which only manufacturers can have access, thus realizing a security hardware tool that, because of its complex design, is less prone to reverse engineering and security attacks. The present work reinforces the use of dielectric metasurfaces as a ubiquitous platform to be used in several key research areas and for future strategic THz photonics applications.

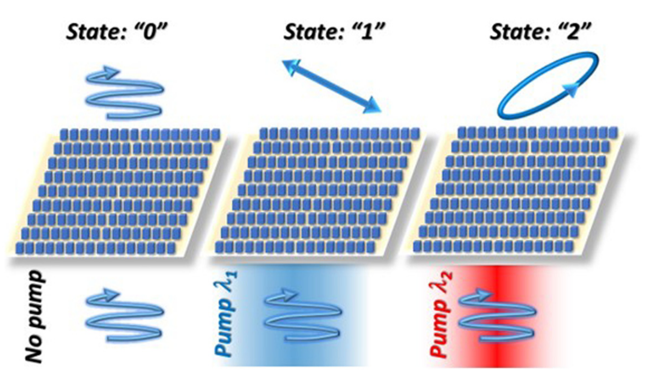


**Fig. 1** Schematic of the silicon 3D pillar metasurface array for polarization modulation and different logic state encoding under different pump wavelengths.

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