

NEWS & VIEWS

Open Access

Electrically tunable solid-state metasurfaces realized by flash localized heating

Qian Sun¹ and Minghui Hong¹✉

Abstract

Electrically programmed metasurfaces provide large modulation depth, high modulation rate, and solid-state component, breaking the limitations of existing modulation methods.

Traditional optical components modulate the wavefront by using the transmission phase accumulation generated by light propagation in the medium. The modulation capability is limited by the modulation mechanism and material properties. The volume is relatively bulky and the function is single, which is difficult to satisfy the miniaturization and integration of optoelectronic devices. Metasurface¹ holds promise for solving this problem based on the generalized refraction law, which is presented as a two-dimensional ultra-thin array plane with artificial subwavelength structures. It can realize complex optical modulation functions by pixelated phase or amplitude modulation on the nanometer scale, which promotes the integration of optical devices in principle.

In recent years, metasurfaces have been widely studied and developed. Typically, the metasurface is designed and manufactured with a fixed optical property, which cannot satisfy the demand of complicated applications, such as being used in beam scanning as zoom lens. Therefore, researchers proposed a novel metasurface with active tuning capability to enhance its practicability. The optical properties of the metasurfaces are expected to be controlled dynamically by introducing external field modulation. At present, potential approaches for dynamic modulation have been reported, such as phase-change materials², liquid crystals^{3,4}, semiconductor materials^{5,6}, two-dimensional materials^{7–9}, and micro-electromechanical system-based actuators¹⁰. However,

the existing modulation methods still face many challenges, such as low tuning rate, weak modulation, and non-solid-state components. Therefore, a new tuning method is required to solve these problems.

In this issue of *Light: Science & Applications*, Dragomir Neshev, Mohsen Rahmani, and their colleagues¹¹ demonstrated a novel electrically tunable metasurface, breaking through the limitations of existing modulation methods.

In this work, the authors introduced an effective method of adapting fast electrical switching by an optical switch, which uses thermo-optical silicon membrane metasurfaces, controlled by electrically driven localized transparent heaters. The schematic of the device is shown in Fig. 1, it consists of a transparent conductive oxide-encapsulated silicon hole array metasurface. When an electric potential difference is applied to the contact, electrons start to travel in the conductive indium tin oxide strip, which creates local heaters on the desired pixel metasurfaces. The temperature of the heater can be controlled by an electronic switch in the drive system. Due to the thermo-optical effect¹², an increase in the metasurface temperature leads to a change in the refractive index of the resonators, which in turn leads to a shift in the resonant wavelength. Therefore, this research converts the electrical switch to local flash heating, which consequently converts to an optical switch.

The designed electrically tunable metasurface exhibits impressive characteristics. This work creatively adopts an asymmetric voltage spike to achieve up to 90% optical modulation depth with the switching time <625 μs. It

Correspondence: Minghui Hong (elehmf@xmu.edu.cn)

¹Pen-Tung Sah Institute of Micro-Nano Science and Technology, Xiamen University, Xiamen 361005, China

© The Author(s) 2023



Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.



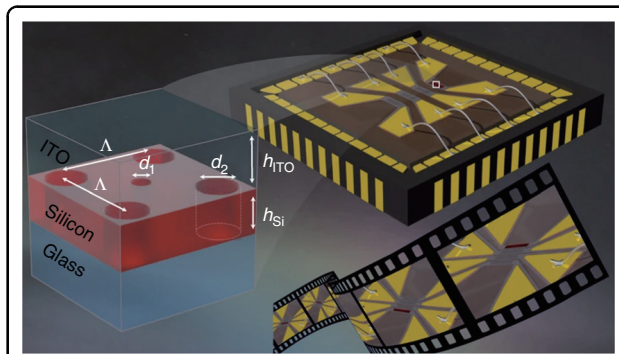


Fig. 1 Electrically switchable metasurface pixels by flash localized heating. Illustration of the fabricated sample, composed of designed nanoholes in a silicon film, so-called hole array metasurfaces, embedded in an ITO transparent heater. The parameters of the design are $h_{Si} = 155$ nm, $d_1 = 78$ nm, $d_2 = 101$ nm, $h_{ITO} = 380$ nm, and pitch $\Lambda = 350$ nm

indicates that the device can work at a switching rate much higher than the video frame rate, demonstrating the ultra-high modulation rate and large modulation depth of the metasurface. Meanwhile, pure solid-state components are employed, which are more robust and stable compared to liquid crystal tunable metasurfaces. Furthermore, the designed metasurface is electronically programmable and CMOS-compatible, improving the efficiency and applicability of the metasurface.

This innovative technology for electrically tunable metasurfaces is strategically important for the development of optical switches. The proposed mechanism fills up the technique blanks for the tunable metasurfaces capable of switching light effectively in the transmission

regime at high frequencies. The development of the metasurface is thus a critical step forward, which will provide unprecedented light manipulation capabilities. This research will have promising applications in flat displays, lidar systems, optoelectronic detection systems, augmented reality devices, and other fields.

Published online: 17 May 2023

References

1. Yu, N. F. et al. Light propagation with phase discontinuities: generalized laws of reflection and refraction. *Science* **334**, 333–337 (2011).
2. Tsai, D. P. Phase-change metasurface slows down light. *Light Sci. Appl.* **10**, 192 (2021).
3. Zhuang, X. L. et al. Active terahertz beam steering based on mechanical deformation of liquid crystal elastomer metasurface. *Light Sci. Appl.* **12**, 14 (2023).
4. Badloe, T. et al. Liquid crystal-powered Mie resonators for electrically tunable photorealistic color gradients and dark blacks. *Light Sci. Appl.* **11**, 118 (2022).
5. Drevinskas, R. et al. Ultrafast laser-induced metasurfaces for geometric phase manipulation. *Adv. Opt. Mater.* **5**, 1600575 (2017).
6. Yang, Y. M. et al. Femtosecond optical polarization switching using a cadmium oxide-based perfect absorber. *Nat. Photonics* **11**, 390–395 (2017).
7. Lu, C. C. et al. An actively ultrafast tunable giant slow-light effect in ultrathin nonlinear metasurfaces. *Light Sci. Appl.* **4**, e302 (2015).
8. Miao, Z. Q. et al. Widely tunable terahertz phase modulation with gate-controlled graphene metasurfaces. *Phys. Rev. X* **5**, 041027 (2015).
9. Zeng, C. et al. Graphene-empowered dynamic metasurfaces and metadevices. *Opto-electron. Adv.* **5**, 200098 (2022).
10. Cong, L. Q. et al. Active multifunctional microelectromechanical system metadevices: applications in polarization control, wavefront deflection, and holograms. *Adv. Opt. Mater.* **5**, 1600716 (2017).
11. Zangeneh Kamali, K. et al. Electrically programmable solid-state metasurfaces via flash localised heating. *Light Sci. Appl.* **12**, 40 (2023).
12. Rahmani, M. et al. Reversible thermal tuning of all-dielectric metasurfaces. *Adv. Funct. Mater.* **27**, 1700580 (2017).