Editorial for the Theories and Applications of Metasurfaces

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Metasurfaces, the two-dimensional counterparts of metamaterials, have shown unprecedented capabilities in the local manipulation of phase, amplitude and polarization of electromagnetic waves from visible light to THz/ GHz waves by tailoring the geometry of antennas. With the advances in theory and design of metasurfaces, they have demonstrated great potentials to realize extraordinary light manipulations, such as colour generation, light bending, focusing, wave plates, vortex beam generation, and holograms. One of the limitations in the practical applications of metasurfaces is low efficiency, which has been overcome by several new-concept metasurfaces, such as reflected metasurfaces, dielectric metasurfaces, and the Huygens' metasurfaces. Although there are other existing problems that need to be completely solved for practical applications, due to the flexibility in the design and the sub-wavelength thickness, the metasurface is one of the best candidates to replace the existing conventional optical components. This special issue highlights the most recent progress in theories and applications of metasurfaces from visible light to THz/ GHz waves, including twelve articles and three review papers.

To understand the underlying physics of metasurface based perfect absorbers, it is very important to explore the scattering properties of an individual element of such metasurfaces, usually referred as nanoantenna. In this issue, Rasoul Alaee and coworkers present a theoretical review on the absorption, scattering, and extinction of both dipole scatterers and regular arrays of such metasurfaces [1], in which they gave an educative analytical approach for outlining the maximum absorption limit of the electrically/magnetically resonant dipole particles and metasurfaces, and put forward the analysis for both of Huygens metasurfaces and Salisbury absorbers in providing perfect absorbers.

Dispersion engineering is essential for spectral utilization in electromagnetic systems. Xiong Li and colleagues review the mechanism, practical applications and recent advancements of the dispersion engineering in metamaterials and metasurfaces [2], in which the contributions of dispersion management in metadevice-based super-resolution imaging/nanolithography systems, planar functional devices, as well as the broadband perfect absorbers/polarization converters are discussed in depth.

In order to meet the needs of practical applications, recently, researchers are working to develop miniaturized and integrated THz system based on metasurfaces. Jingwen He and Yan Zhang have reviewed the recent developments in the metasurfaces for polarization and field modulation in the THz waveband, such as principles and the applications of the static THz modulators and the tunable THz devices[3], in which a number of THz field modulated metasurfaces are illustrated, and a series of active metasurfaces triggered by electricity, temperature, and light both in spectrum and field modulations are summarized.

The dependence of the dielectric metasurface's optical responses on the incidence angle of the input light field has been investigated experimentally and numerically [4]. The transmittance of the Huygens' metasurfaces depends on the incidence angle and is sensitive to polarisation for oblique incidence. With the increase of the incidence angle, the two dipole resonances are shifted out of the spectral overlap and the resonant features appear as pronounced transmittance minima. Meanwhile, the resonances of this metasurface can be tuned into spectral overlap and regain the high resonant transmittance characteristic of Huygens' metasurfaces at a particular incidence angle. Tongming Liu and colleagues propose a distinct approach for polarization conversion in an optical fiber by introducing an all-dielectric metasurface in it [5], which has been proven to be compact, efficient and robust. Based on this approach, nearly perfect polarization conversion from the linear polarization mode to various other polarization modes can be achieved, including its cross-polarization mode, left/right-handed circular polarization mode, and also vector modes with radial and azimuthal polarizations. Based on a holographic configuration and a spin-dependent metasurface design, Zhenwei Xie and coworkers propose and demonstrate an on-chip spin-controlled OAM-mode directional coupler [6], which can couple the OAM signals to different directions due to its topological charges. Furthermore, the directional coupling function can also be switched on/off by altering the spin of the incident beam. Jun Guo and coworkers propose a nonlinear metasurface made of a few-layer graphene and a metal grating [7], in which the graphene plasmons can be excited in this configuration efficiently and two different kinds of resonances are also found. Meanwhile, the metasurface can also be used in optical bistability, and the low-threshold hysterical behavior with only a few $MWcm^{-2}$ is observed due to the large third-order nonlinear response of graphene and the strong localized field enhancement. Tianyao Zhang and coworkers propose the design and realization of a linear to circular polarization converter based on metasurfaces using achiral two-fold mirror symmetry Ω-shaped antennas [8], which are composed of a ground metal plane, a spacer dielectric layer and an antenna array, leading to a high conversion efficiency and broad operating bandwidth in the near infrared regime.

Based on the coupled mode theory, Huijie Guo and coworkers propose a theoretical criterion that can help researchers design structures exhibiting wide-band optical transparent window with diminished transmittance fluctuations [9]. They designed a four-layer structure (with a total thickness of 36 mm) through solving the proposed criterion, and experimentally demonstrate that it exhibits a flat OTW within the 3.7–5 GHz range, with transmittance fluctuations smaller than 10 percent. Tie Jun Cui and his team [10] propose fast and accurate designs to large-scale and low-profile transmission-type anisotropic coding metasurfaces with multiple functions in the millimeter-wave frequencies based on the antenna-array method. In consideration of the configuration of the utilized computer, they implemented a transmission-type coding metasurface at 60 GHz with the size of $16\lambda \times 16\lambda$ by 3-bit anisotropic codes to compare the performances of the antenna-array method with full-wave commercial software. The good agreement between simulation and experimental results proves the accuracy of antenna array method, which also costs less time and memory.

We would like to thank all of our contributors to this special issue. We also hope that the theory and the applications of the metasurface reported in this special issue can be utilized in experiments of many researchers and contribute to the progress in the understanding of the metasurfaces.

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