PHOTONICS INSIGHTS

Enriching surface plasmons with metasurfaces

Fei Ding* and Sergey I. Bozhevolnyi*
Centre for Nano Optics, University of Southern Denmark, Odense, Denmark

Surface plasmons (SPs), or SP polaritons, are electromagnetic (EM) surface waves that propagate freely along metal–dielectric interfaces while being tightly localized in the perpendicular direction due to the interaction with collective oscillations of electron plasma in the metal[1]. Therefore, SPs become two-dimensional (2D) manifestations of EM waves, with potentially very large wavenumbers near the SP resonance, thereby paving the way for many exciting phenomena, such as light focusing beyond the notorious optical diffraction limit and directing EM energy to the nanoscale[2]. Although SPs have proven to be a unique platform for integrated optoelectronic devices where light and electric signals can be simultaneously processed, implementing compact on-chip SP components, such as directional couplers, multiplexers, and lenses, remains a complicated and arduous task. Recently, a new flourishing research field, optical metasurfaces composed of extremely thin nanoantennas[3,4], has rapidly revolutionized SP devices with ultracompact size and superior performance, inspired by the pioneering work done by Zhou's group in the microwave range[5].

Writing in *Photonics Insights*, Xu *et al.*[6] have reviewed the most recent advances in the field of metasurface-optics inspired SP devices. The review starts with the fundamentals of SPs, including the dispersion relation, propagation properties, material platforms, and characterizing technologies. A comprehensive discussion of numerous meta-optics inspired functional SP devices is then provided, where they highlight the fancy meta-optics for coupling, tailoring, and scattering SPs. Compared to traditional prism or grating couplers/decouplers, the metasurface-based SP counterparts exhibit the advantages of compactness, directionalities, efficiencies, and diversified functionalities[6,7]. In particular, multiplexed SP coupling and wavefront shaping have been emphasized by the authors, which can be realized by utilizing different degrees of freedom of EM waves, such as polarization, wavelength, and optical angular momentum (OAM). As such, the meta-optics inspired SP platform offers a promising route to on-chip multifunctional plasmonic devices and systems. Following the SP devices, Xu *et al.* focus on meta-optics empowered nascent SP applications. They review recent progress in all-optical logic gates, metasurface-decorated waveguides, optical tweezers, and polarimeters. They further summarize the overviewed device configurations and outline a perspective on implementing meta-optics inspired SP devices for real photonic applications by solving several issues, such as dissipative loss, sensitivity to surface defeats, and efficiency.

Among all possible directions mentioned in the review[6], we believe active SP meta-devices would be intriguing to meet the increased demand for information capacities and device functionalities by incorporating active elements (e.g., phase-change materials, 2D materials, transparent conducting oxides, and liquid crystals)[8–10], functionalities that can further be improved by polarization multiplexing, wavelength multiplexing, OAM multiplexing, and other techniques. Another very promising direction beyond the scope of the review could be SP-enabled quantum metasurfaces for the development of advanced single-photon sources with superior properties[11,12]. By properly tailoring the emission of SPs that are nonradiatively excited by a deterministic quantum emitter, collimated beams of single photons with desirable polarization and wavefront distributions can be realized[13], thus enriching even further SP-based device configurations.

This comprehensive review is timely and covers a wide range of interesting topics in SP devices based on metasurfaces, which we believe will greatly help young researchers enter this fascinating field.

*Address all correspondence to Fei Ding, feid@mci.sdu.dk; Sergey I. Bozhevolnyi, seib@mci.sdu.dk

© The Authors. Published by CLP and SPIE under a Creative Commons Attribution 4.0 International License. Distribution or reproduction of this work in whole or in part requires full attribution of the original publication, including its DOI. [DOI: 10.3788/PI.2023.C02]

References

1. S. A. Maier, *Plasmonics: Fundamentals and Applications* (Springer Science & Business Media, 2007).
2. D. K. Gramotnev and S. I. Bozhevolnyi, "Plasmonics beyond the diffraction limit," *Nat. Photonics* **4**, 83 (2010).
3. F. Ding, A. Pors, and S. I. Bozhevolnyi, "Gradient metasurfaces: a review of fundamentals and applications," *Rep. Prog. Phys.* **81**, 026401 (2018).
4. S. Sun *et al.*, "Electromagnetic metasurfaces: physics and applications," *Adv. Opt. Photon.* **11**, 380 (2019).
5. S. Sun *et al.*, "Gradient-index meta-surfaces as a bridge linking propagating waves and surface waves," *Nat. Mater.* **11**, 426 (2012).
6. Q. Xu *et al.*, "Meta-optics inspired surface plasmon devices," *Photon. Insights* **2**, R02 (2023).
7. F. Ding and S. I. Bozhevolnyi, "A review of unidirectional surface plasmon polariton metacouplers," *IEEE J. Sel. Top. Quantum Electron.* **25**, 4600611 (2019).
8. Q. He, S. Sun, and L. Zhou, "Tunable/reconfigurable metasurfaces: physics and applications," *Research* **2019**, 1849272 (2019).
9. F. Ding, Y. Q. Yang, and S. I. Bozhevolnyi, "Dynamic metasurfaces using phase-change chalcogenides," *Adv. Opt. Mater.* **7**, 1801709 (2019).

10. T. Gu *et al.*, "Reconfigurable metasurfaces towards commercial success," *Nat. Photonics* **17**, 48 (2023).
11. Y. Kan *et al.*, "Metasurface-enabled generation of circularly polarized single photons," *Adv. Mater.* **32**, 1907832 (2020).
12. C. Wu *et al.*, "Room-temperature on-chip orbital angular momentum single-photon sources," *Sci. Adv.* **8**, eabk3075 (2022).
13. Y. Kan and S. I. Bozhevolnyi, "Molding photon emission with hybrid plasmon-emitter coupled metasurfaces," *Adv. Opt. Mater.* **10**, 2102697 (2022).