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Photonic metadevices: introduction

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The research field of metamaterials is reaching its maturity, encouraging one to actively search for real-life applications of the metamaterial concept. This issue features works covering various aspects of metadevices—a natural progression of the paradigm that aims to accommodate and dynamically control metamaterial response in miniature photonic and optoelectronic devices. © 2017 Optical Society of America

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Metamaterial research has seen a tremendous growth over nearly two decades, with a number of fascinating theoretical proposals and multiple experimental demonstrations. The purpose of this special issue is to consolidate the latest research on the so-called metadevices—a natural progression of the metamaterial concept that aims to accommodate dynamically tunable and nonlinear tailored material response in the form of compact photonic and optoelectronic devices with novel or enhanced functionalities. The ground for success of this field lies in the very nature of metamaterials as optical media with properties that can be engineered from the very beginning according to one's needs. In particular, contrary to the conventional optics, where one has to rely on the relatively small range of available material parameters and functionalities, key properties of metamaterials, including linear and nonlinear optical behavior, can be tailored in a desired way. The possible approaches span from a mere resonant enhancement of nonlinear response to sophisticated design of metamaterial elements or their entire structure, which may implement semiconductor devices or genuine material combinations. As a result, the range of potential applications of the original metamaterial's concept expands dramatically to include, for example, optical switching, sensing, imaging, lasing, active beam steering, and wavefront manipulation. With data processing and waveguiding being embedded in a metadevice at the material's level, the paradigm promises a substantial increase in photonic integration and energy efficiency far beyond that of bulk optical components and silicon photonics.

The unique combination of material properties that surpass (or complement) those available in nature, dynamic control, and high degree of integration renders metadevices as building blocks of future nano-photonic circuits. The collection of works selected for this feature issue serves to present recent examples of metadevices with various functionalities across visible to microwave spectral domain. Voroshilov and Simovski [1] suggest and theoretically analyze universal light-trapping structures for thin-film solar cells (TFSC) that should increase the efficiency of third generation organic and perovskite TFSCs. Ramaccia *et al.* present the design of sub-pixels based on super-spherical nanoparticles operating in the blue, green, and red parts of the spectrum, which could make transparent displays feasible and practical [2]. By manipulating directly localized spoof plasmons in corrugated metamaterial resonators, electronically switchable and tunable band-pass filters have been proposed and experimentally demonstrated in the microwave spectral range by Zhou *et al.* [3]. Resonant accumulation of magnetic energy in silicon nanocylinders featuring 26-fold field enhancement is theoretically investigated in the optical and near infra-red regions by Baryshnikova *et al.* [4], who suggest possible applications in detecting magnetic optical transitions. Klushmann *et al.* [5] study theoretically and numerically a photonic metadevice comprising a microdisk resonator and a high-density gold nanoparticle film deposited on its top. Their robust metamaterial-inspired approach allows the extension of the whispering gallery mode outside the microdisk resonator, leading to a notable increases in the device sensitivity, as desired by biosensing applications [5]. Miri and Alù explore meta-waveguides based on one-dimensional arrays of coupled optomechanical cavities [6]. Their work paves a way toward metadevices in which strong optomechanical coupling can overcome certain limitations of passive metamaterial systems. Li *et al.* propose zero-index metacrystals for the visible range, which can find use in many practical applications as wide-bandwidth and low-loss achromatic photonic devices for steering light propagation, arbitrary wavefront conversion, directional emission, and obstacle-free light guiding [7].

This issue also includes several works on metasurfaces, which are currently deemed the most promising artificial material systems for real-life applications. These works are focused on the unusual properties of such surfaces that in some sense can be regarded as anomalous [8–16]. Namely, metasurfaces made of non-bianisotropic complementary split-ring resonators by Rodrigues-Ulibarri *et al.* can operate in the millimeter-wave domain as angular selective devices with strong rejection at normal incidence [8]. A specific design of all-dielectric gradient metasurfaces by Tsitsas and Valagiannopoulos [9] enables significantly enhanced anomalous reflection with simultaneously suppressed ordinary reflection predicted by Snell's law. A nanoparticle array can suppress reflection from a high index material surface [10]. Babicheva *et al.* [10] develop a semi-analytical model that gives a deep insight into the effect. New in metamaterials application, the graphene-hBN multilayered material system explored by Hajian *et al.* offers enhancement of spontaneous emission, hyperlensing, and waveguiding [11]. Dark mode metasurfaces for sensing of optical phase difference with sub-radiant modes and Fano resonances are proposed by Roberts *et al.* [12]. Roberts *et al.* [13] suggest that the metasurfaces can be used for out-coupling the energy from high-index dielectrics and study the limit of its efficiency. This issue also offers new insights into the effect of perfect absorption in metamaterials by Üstün et al. [14], a detailed account of modeling analytically passive and active metamaterials by Chipouline and Küppers [15], and tunable terahertz metamaterials fabricated by fiber drawing by Fleming *et al.* [16].

We are confident that this collection of featured works, while only touching the tip of the iceberg, gives a faithful representation of the latest research on metadevices and their possible applications.

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