

Guest Editorial: Dielectric Nanoresonators and Metamaterials

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High-refractive-index (HRI) dielectric nanostructures, and in particular semiconductors, are attracting significant attention in Optics and Photonics nowadays for exhibiting strong (electric and magnetic) multipole optical resonances with low dissipative losses. Since the emergence of magnetic-dipole resonances in semiconductor nanoparticles, or in sub-wavelength HRI particles in general, was theoretically proposed¹⁻³ and experimentally demonstrated^{4,5}, a wealth of unique optical properties, including strong directionality effects⁶⁻⁸, have been unveiled, stemming from their resonant nature that renders them excellent nanoresonators⁹.

Moreover, dielectric nanoparticles have been exploited as constituting new building blocks of more sophisticated arrangements. Especially relevant to applications is the configuration consisting of two-dimensional arrays, which in the non-diffractive regime are termed metasurfaces¹⁰ (metagratings otherwise), of such nanoresonators, as all-dielectric metasurfaces or metadevices¹¹⁻¹⁵. A wealth of new or enhanced fundamental light-matter interactions at the nanoscale have been recently investigated using these HRI particles¹¹⁻¹⁵, leading to enhanced directionality and Raman scattering, novel Brewster effects, zero-index materials, metalenses for miniaturized planar optics, sharp Fano resonances, and highly efficient sensing, etc. Besides, semiconductor nanostructures also offer longer excited-carrier lifetimes, may exhibit intrinsic nonlinearities, and can be electrically doped and gated, or optically pumped, to realize subwavelength active optoelectronic devices.

The field of dielectric nanoresonators and metamaterials has rapidly evolved in recent years from the fundamental standpoint, being now mature to develop a variety of appealing applications. The “Dielectric Nanoresonators and Metamaterials” Special Topic of *Journal of Applied Physics* highlights the state-of-the-art of emerging applications in Nanophotonics enabled by optically resonant semiconductor nanostructures, to realize unique functionalities and/or to deploy novel photonic devices. An overview of the topics of the articles published in the collection is given below.

First, we highlight those works that exploit the resonant properties of single (or multiple) HRI resonators. In this regard, it is evident that engineering electric and magnetic dipole/multipole resonances is crucial for a variety of applications such as nanoantenna directionality and Fano resonances and complex interference effects. A few works indeed explore various types of resonances in HRI particles and such as: resonances in lossy media¹⁶, electron-beam excitation of supermodes in dimers¹⁷, toroidal

resonances in cylinder pentamers¹⁸, Fano resonances^{19,20}, and field enhancement in heterostructured semiconductor nanowires²¹ or Q-factor enhancement in coaxial disks.

Others emphasize nanoantenna directionality: e.g. asymmetric light scattering by silicon nanopylamids²² or photonic-jet effects^{23,24}. Finally, more complicated phenomenology is also evidenced, such as spin-orbit interactions²⁵ and non-linear frequency conversion²⁶. All fascinating features of dielectric nanoresonators beautifully merge in the review by Bidault et al²⁷. Therein, the authors present the recent advances in the use of dielectric nanoantennas to not only enhance or control decay rates of both electric and magnetic emitters, but also to manipulate their radiation pattern through the coherent excitation of electric and magnetic modes, discussing in turn perspectives of this emerging field in solid-state light emission.

Next, we describe those works that require an array of HRI resonators: metasurfaces, metagratings or related structures. Bear in mind, though, that most of them, apart from the relevance of the periodic arrangement, rely on the resonant properties of HRI particles too²⁸⁻³⁰.

Interestingly, HRI dielectric metasurfaces and metastructures are shown to hold promise for a variety of flat optical devices. These include devices providing control over the polarization of light, such as a tunable polarization state converter/synthesizer based on a thermo-optically actuated, resonant semiconductor metasurface³¹; or a device with broadband active polarization control functionalities including reconfigurable polarizing beam splitting and arbitrary linear output polarization rotation³². They also include devices allowing control over the amplitude and/or phase of reflected and transmitted fields³³, either static or dynamic, such as angular-independent spectral filters³⁴, multi-angle retroreflectors³⁵, anti-reflection coatings for LED applications³⁶, magnetic mirrors³⁷, optical components with sophisticated, non-discrete wavefront engineering through impedance-matched metasurfaces³⁸, or double-layer graphene optical modulators³⁹. Finally, devices exhibiting other functionalities, such as directional photoluminescence emitters⁴⁰, refractive-index sensors⁴¹, and even thermal rectifiers using gold-vanadium dioxide micro-gratings⁴². In addition, fabrication of a new type of Mie-resonant metasurfaces based on SiGe islands is reported⁴³.

Particularly enlightening is the perspective examining the rich phenomenology arising from the interaction of semiconductor metasurfaces with short laser pulses, with regard to enhanced nonlinear-optical response and even spatiotemporal shaping⁴⁴. Other configurations and/or phenomenologies are also covered in this Special Topic, such as Kerker effects in periodic waveguides composed of high-index dielectric nanocylinders⁴⁵, negative refraction through concave metamaterials⁴⁶, ferroelectrics⁴⁷, and light-harvesters in nature as effective antennas through a metamaterial design⁴⁸.

In summary, all-dielectric resonant nanostructures have emerged as a promising platform for nanophotonics applications over the past few years. Since the early theoretical predictions of the artificial magnetic response of dielectric nanoparticles at optical frequencies, the field has witnessed an accelerated expansion and steadily moved towards the realm of applications.

Of particular importance is the use of dielectric nanostructures for metasurface applications and, in particular, for flat optical devices. The unprecedented control offered by these devices in manipulating the polarization, amplitude and phase of light, has benefited from the low optical losses of dielectrics to achieve efficiency levels realistically close to those required for industrial applications. Not only are these flat optical devices called to replace traditional ones, but rather to expand the range of achievable functionalities, as seen in many of the articles in the “Dielectric Nanoresonators and Metamaterials” Special Topic.

Going beyond passive functionalities, new frontiers have recently opened in the field by considering active, non-linear or dynamically tunable systems. In this regard, the use of resonant dielectrics or semiconductors to enhance and tailor light emission processes holds promise to realize more efficient light sources in the nanoscale. On the other hand, the large field concentration inside dielectric resonators can provide the perfect platform to maximize non-linear processes as well as to take advantage of changes in the material properties as to achieve dynamic tunability. Thus, we can only expect that the range of applications of these novel photonic building blocks will continue to grow in upcoming years, opening new exciting opportunities in diverse areas, such as imaging, sensing and ranging, photonic and quantum circuitry, displays, and many more.

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