Hybrid organic–inorganic materials for photonic applications

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Abstract: This novel joint feature issue on "Hybrid organic–inorganic materials for photonic applications" in Applied Optics and Optics Materials Express comprises 14 papers on liquid crystals, polymers, photoconductive materials, and gratings and filters. It is hoped that this feature issue encourages and stimulates further research to into hybrid materials with enhanced linear and nonlinear optical properties, their mechanisms of operation, and their applications.

OCIS codes: (160.2100) Electro-optical materials; (160.3710) Liquid crystals; (160.5320) Photorefractive materials; (160.5470) Polymers; (160.1245) Artificially engineered materials; (160.4236) Nanomaterials.

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It is well-known that many natural materials consist of inorganic and organic building blocks where the inorganic part provides mechanical strength and an overall structure to the natural objects, while the organic part delivers bonding between the inorganic building blocks and/or the soft tissue. The most obvious advantage of inorganic–organic hybrids is that they can favorably combine the often dissimilar properties of organic and inorganic components in one material. The study of such materials has encouraged many materials researchers to use a biomimetic approach to artificially manufacture many novel materials for use in applications, such as scratch-resistant coatings, dental fillings, fire retardants, super-capacitors and energy production and storage devices, etc. Electro-optical applications of hybrids include light-emitting diodes, photodiodes, solar cells, sensors (including plasmonic and biosensors), field-effect transistors, and efficient nonlinear optical devices. Other novel optical applications include organic–inorganic-based meta and plasmonic materials for imaging and sensing.

Hybridization of organic and inorganic materials also opens up yet another new and exciting area in applied optics. The various forms of hybrids in this special issue have organic and inorganic components, where the inorganics modify the optical and electric properties of the organics. In addition, the organic matrix may provide a flexible structure as well as order/structure to the nanomaterials [i.e., nanoparticles, liquid crystals (LCs), etc.]. The optical and electric properties of LCs have been shown to be enhanced using nanoparticles. Furthermore, it has also been reported that LCs can be strongly influenced by polymer materials in terms of structuring, ordering, and stabilizing. Outside their role in LC devices, polymers themselves can be hybridized with nanomaterials, modifying the refractive index, birefringence, and source of charge donors/acceptors. Devices exploring these phenomena may find applications in optical beam coupling, optical switches, spatial and temporal filters, tunable photonic crystals, beam shaping, optical displays, and hybridized light valve technologies.

Specifically, this feature issue consists of 14 papers comprising four sections: liquid crystals (Lorenz et al. [1], Rudzki et al. [2], Garbovskiy and Glushchenko [3], Lavrič et al. [4], and Yaroshchuk et al. [5]); polymers (Nabil et al. [6], Minasyan and Galstian [7], Uklein et al. [8], Nazarova et al. [9], and Sassa et al. [10]); photoconductive materials (Bortolozzo et al. [11] and Mercado-Zúñiga et al. [12]); and gratings and filters (Sheremet et al. [13] and Danaeifar et al. [14]). The papers by Uklein et al. and Sassa et al. appear in Optical Materials Express, while the rest appear in Applied Optics.

In the first section, Lorenz et al. [1] investigated the influence of ferroelectric nanoparticles on the realignment of the LC director upon the application of an electric field. In this invited paper, LC nanodispersion with BaTiO3 ferroelectric nanoparticles showed a more pronounced reorientation with a reduced threshold voltage compared to the undoped LC. Rudzki et al. [2] studied the influence of various-size harvested barium titanate nanoparticles on the properties of ferroelectric liquid crystal (FLC) using electro-optical and dielectric methods. There is a reduction of the switching time with decrease of BaTiO3 particle size and the (Goldstone mode) viscosity. Garbovskiy and Glushchenko [3] explore how optical and BaTiO3 and PbTiO3 ferroelectric properties of stressed ferroelectric nanoparticles set a limit on the performance of optical and electro-optical devices. Lavrič et al. [4] present a theoretical model accounting for the impact of anisotropic MoS2 nanoparticles on the blue phase stability region in chiral LC, and validate the model by high-resolution calorimetric and optical measurements. This study revealed that the geometry of the nanoplatelets played an important role in the stabilization of different blue phase structures. Yaroshchuk et al. [5] investigated photoresponsive electro-optical composites comprising cholesteric LC doped with carbon

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nanotubes, demonstrating a dual-mode operation with the optical switching between reversible and memory mode. They showed that LC composites with homeotropic anchoring exhibit a transition from fingerprint texture to homeotropic nematic texture in the course of a photoinduced unwinding of the cholesteric helix.

Nabil et al. [6] applied polymer dispersed liquid crystal (PDLC) as cladding material in a polymer-based variable optical attenuator. The PDLC-based waveguide was electro-optically modified at low operating voltages without the need of alignment layer as in the case of LC. Minasyan and Galstian [7] created surface polymer stabilized structures using dual frequency controlled LC with thin reactive mesogen films. These devices greatly improved contrast and polarization independence of light scattering, and achieved very short transition times when switching from low to high frequency. Uklein et al. [8] reported on photoinduced modifications of the refractive index of nanoparticulate TiO2-pHEMA organic–inorganic hybrids. Their results suggested that refraction index variations of the order of 0.005 are attainable, making these materials candidates for applications in optoelectronics. Nazarova et al. [9] synthesized an anisotropic organic/inorganic nanocomposite material using SiO2 nanoparticles in a side-chain azopolymer. They observed about 20% enhancement of the photoinduced birefringence in these composite materials compared to nondoped samples. Sassa et al. [10] studied the influence of a transient dark current on the buildup dynamics of photorefractive polymer index gratings. They concluded that transient dark current flow is an important factor to be considered to optimize conditions for pulsed voltage-assisted PR effects.

Bortolozzo et al. [11] developed a LC light-valve (LCLV) and a self-defocusing medium for near-infrared applications using GaAs:Cr photoconductive substrates. The LCLV displays an efficient behavior as an optically addressable transmissive spatial light modulator, with potential future applications in interferometric systems or in thermal sensors due to the large Kerr-like nonlinear coefficient. Mercado-Zúñiga et al. [12] developed a photoconductive logic gate based on platinum decorated carbon nanotubes, and characterized the electrical and nonlinear optical properties of these materials. The photoconductive logic gate function OR was experimentally demonstrated.

In the last section of this joint special issue, the invited paper by Sheremet et al. [13] showed the results of recording polarization gratings in a combined LC cell made of a substrate covered with a photosensitive chalcogenide orientation layer and a reference substrate covered with a rubbed polyimide film. They showed that the application of an ac-field caused a strong increase of the first order diffraction efficiency. Danaeifar et al. [14] demonstrated that a 2D sheet of graphene can be used as a simple band-pass filter in terahertz and infrared frequencies. The effects of various material and device parameters on surface plasmon polariton waves and filter specifications were numerically depicted. This material can operate in a wide frequency range, with potential uses as telecommunication transducers and infrared cameras.

In light of the rapid progress in this area, it is hoped that this novel joint Feature Issue in Applied Optics and Optical Materials Express encourages and stimulates further research into hybrid materials, their mechanisms of operation, and their applications. The editors feel that the future of optical hybrid materials will continue to bring to fruition new materials with enhanced linear and nonlinear optical properties, opening new doors to unexplored application and the improvement of performance of current technologies. Potential areas to explore, in addition to the numerous areas explored in this Feature Issue, are optical bio-sensors, optical metamaterials, plasmonics, and interactions at the boundaries of the organic and inorganic components of hybridized materials.

Feature editors

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