

Feature issue introduction: optical materials for flat panel displays

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Abstract: This feature issue on “Optical Materials for Flat Panel Displays” of *Optical Materials Express* spotlights recent advances in optical materials for information display applications. It comprises 12 papers primarily on liquid-crystal and light-emitting materials and their devices. It is hoped that the present special theme issue encourages and stimulates further research endeavors into novel optical materials with improved optical or electro-optical properties, their mechanisms of operation, and their promoted device performance for potential flat-panel-display applications.

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OCIS codes: (120.2040) Displays; (160.2540) Fluorescent and luminescent materials; (160.2750) Glass and other amorphous materials; (160.3710) Liquid crystals; (160.5470) Polymers; (230.3670) Light-emitting diodes.

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Flat panel displays are ubiquitous nowadays and have become indispensable to many people both at work and at home. The current \$100B liquid-crystal-display market sheds light on the truly amazing triumph of research and development of information displays in general. Undoubtedly, the success of these modern information displays such as smartphones and TVs stems fundamentally from the scientific and technological advancement in materials research, with optical materials to be one of the key components. Organic and inorganic optical materials for display applications include but not limited to liquid crystals (LCs), (photo)alignment layer materials, reactive mesogens, light-emitting diodes (LEDs) and organic LEDs (OLEDs), phosphors, electroluminescent materials, quantum-dot materials, field emitters, electrophoretic and electrochromic materials, dyes and pigments and their dispersions, polymers and polymeric composites, transparent oxide and substrate materials, optical plates and films, and other passive component materials applied to various 2D and 3D emissive displays, flexible displays, non-emissive displays and projection displays.

Due to the great impact of flat panel displays on our daily life, it is highly significant to publish a special issue of *Optical Materials Express*, featuring a wide spectrum of latest research endeavors in optical materials for flat panel displays. Specifically, this special theme issue consists of 12 papers on "Optical Materials for Flat Panel Displays," of which four are invited articles. The collection can be divided into four sections (or categories). There are seven papers related to LC materials and device properties (Aya *et al.* [1], Yoshida *et al.* [2], Inoue, Yoshida, and Ozaki [3], Sutormin *et al.* [4], Haba *et al.* [5], Momoi *et al.* [6], and Ma *et al.* [7]). Three are concerned with organic compounds for OLEDs (Lee *et al.* [8], Baek *et al.* [9], and Feng [10]). One focuses on luminescent crystalline materials for white LEDs (Qi *et al.* [11]), and one is in the area of glass and other amorphous materials (Damak *et al.* [12]).

The publication of such a special issue featuring the research of blue phases for display applications is timely. Two articles on blue phase LCs are included in this focus issue. In their invited paper [1], Aya and coauthors present their study of blue phases with a record-wide temperature range of about 40 °C in an asymmetric bent dimer comprising a rod mesogen linked together with a cholesterol mesogen. The temperature range is the widest in bent-shaped chiral single-compound systems, which is comparable to that of known high-quality mixture systems consisting of a chiral or achiral host in addition to a chiral dopant. Highly stable electro-optical switching is possible even in a supercooled blue phase without transforming the blue phase to the cholesteric phase. This work is unquestionably novel and of high impact because no polymer stabilization is involved. Apart from the desired fast and stable electro-optical switching based on the Kerr effect, the electrostriction response is small and slow, which are ideal for display applications. The second paper on blue phases is contributed by Yoshida *et al.* [2], who study the secondary electro-optical Kerr effect complicated by photoelasticity in cubic blue phase LCs through simultaneous measurement of the polarized reflection spectrum and transmitted phase. This research in the area of blue phase LCs is particularly important for the development of LC displays with one of the main challenges being the response time of the LC device. The paper focuses on the refractive-index change contributed by the slow component under application of external electric field and demonstrates that the change can be repressed by polymer stabilization of the blue phase LC.

In the study of a microsecond response in a LC/polymer composite [3], Inoue, Yoshida, and Ozaki explore the electro-optical effect in a uniformly mixed structure made from a nematic LC mixture dispersed with a precursor of 30-wt% crosslinkable mesogenic monomer. Unlike a typical polymer-dispersed LC, the resulting composite formed after

photopolymerization exhibits no observable domains to scatter light [13]. The mechanism of the electro-optical switching is investigated through a combination of scanning electron microscopy, Fourier-Transform infrared spectroscopy and visible spectroscopy. Strong evidence suggests that the change in birefringence is due to an effective medium effect where the non-polymerizable LC molecules confined in nano-sized volumes are reoriented along the direction of field.

A new concept for operation of LC devices was proposed by the Nobel-Prize-winning physicist Pierre-Gilles de Gennes (1932–2007) in 1975. A common feature of this concept is that the external stimuli, such as temperature, light or electric field, do not directly affect the orientation of the molecules in the LC bulk but they influence the alignment properties of LC cell substrates. One of the effective methods to modify the anchoring properties by voltage is based on the employment of ionic surfactants added to LC. A drawback of such an ionic-surfactant method to control the LC configuration transition is the correspondingly slow switching action. Now as presented in their invited paper [4], Sutormin and colleagues have resolved the hurdle, achieving a substantial performance enhancement by exploiting two approaches to remarkably shorten both the field-on and field-off times in ionic-surfactant-doped nematic cells. The relaxation time (field-off time) in their experiment is decreased to 11 ms, which is close to the dynamic switching parameter of conventional LC displays. Accordingly, applying the method for electrically controlled anchoring transitions to LC cells seems to be an effective approach for the development of the novel type of LC displays.

In addition to [4], two more papers focusing on the LC alignment effect are also compiled in this special-issue collection [5,6]. Haba *et al.* [5] report a spontaneous vertical alignment technique based on a mixture of nematic LC doped with a polypropylene imine-based mesogenic dendrimer. Although similar materials are previously known to impose homeotropic alignment when they are mixed with nematic materials [14,15], the authors have added in this work some new findings on this subject. They show the condition under which the dendrimer is adsorbed on the substrate surface and unravel the relationship between the alignment ability and the molecular structure. These details are important for display applications. In a quite interesting paper by Momoi and co-workers [6], rheological properties of rubbed polyimide films for LC alignment are described. They monitor an orientation change of the nematic director after the prolonged application of an AC field. Compared with their earlier publication [16], this article definitely provides a new insight, shedding light on the relationship between the shear modulus and the electric field strength by utilizing the Kelvin–Voigt model.

The last paper on the research of LCs is written by Ma and coauthors [7]. The authors devise a way to keep the temperature of a LC cell within a particular range. Using a layer of aggregated carbon nanotubes (i.e., buckypaper) with high electrical and thermal conductivity as an attachment to a cholesteric LC cell and allowing the buckypaper to function as a thin-film resistance heater, the authors show the feasibility of their approach and demonstrate the heating effect of applied voltage and the temperature response of the cell.

There are two papers, both invited, focusing on blue-emitting materials for OLEDs [8,9]. Lee *et al.* [8] describe the synthesis of two new indenopyrazine derivatives containing high-photoluminescence-efficiency phenanthrene or pyrene side groups for blue and white OLED applications. The synthesized materials have been characterized by various techniques and the device performance has been revealed. The result suggests that the quantum efficiency of the resulting indenopyrazine emitter increases with increasing photoluminescence efficiency of the side group; it clearly shows that the maximization of electroluminescent efficiency of the final emitters pivot on the side group's high efficiency. In the paper by Baek and colleagues [9], an asymmetrically limb-structured blue-emitting anthracene derivative is proposed. The physical and device properties are studied. This paper presents a well-rationalized approach to tuning anthracene derivatives for use as improved blue emitters in OLEDs. It takes the classic 9,10-dinaphthyl anthracene, the ubiquitous blue emitter, and adds additional functionalization to break up solid-state interactions and to tune the optical gap.

In the paper [10] entitled “Dependence of the dynamics of exciton transport, energy relaxation, and localization on dopant concentration in disordered C545T-doped Alq₃ organic semiconductors,” Feng proposes a dynamic scenario detailing possible paths of the exciton transport (jump) among the host molecules tris(8-quinolinolato)-aluminum (Alq₃) and the competition of the exciton transport from the host into the deep site traps (localized states) and aggregations. Scanning electron microscopy, photoluminescence and photoluminescence excitation spectroscopy, and low-temperature (10 K) transient luminescence measurement are performed on various Alq₃ organic semiconducting samples containing 10-(2-benzothiazolyl)-1, 1, 7, 7-tetramethyl-2, 3, 6, 7-tetrahydro-1H, 5H, 11H-benzo[*l*] pyrano[6, 7, 8-*ij*] quinolizin-11-one (C545T) at distinct dopant concentrations, 1, 3, 5 and 7 wt%. Although this report is limited to the C545T-doped Alq₃ system, the results can be of help in understanding of operation mechanisms as well as device designs for general guest–host systems in OLEDs.

To promote white LEDs for lighting and information display, Qi *et al.* [11] develop a new type of luminescence materials based on fluorosilicate apatites of Eu-doped M₂Y₃[SiO₄]₃F (M = Sr, Ba). The resulting materials (namely, Sr₂Y₃[SiO₄]₃F:Eu and Ba₂Y₃[SiO₄]₃F:Eu) exhibit rich luminescence characteristics due to Eu³⁺ and Eu²⁺ ions, depending on the preparation conditions. Eu-color-centers and the luminescence mechanism are discussed by investigating the steady-state photoluminescence and dynamic spectra. These samples are characterized by their tunable luminescence colors, high quantum efficiencies, as well as efficient excitation in the near ultraviolet and blue bands.

Damak and coauthors’ paper [12] deals with an experimental study of the optical properties of Er³⁺-doped tellurite (Er:TZPPN) glass. Spontaneous transition probabilities, fluorescence branching ratios and radiative lifetimes are evaluated. The stimulated emission cross-section is calculated and the chromaticity coordinates in CIE 1931 color space are determined for the glass upon excitation at 490 nm. The spectroscopic results point out that the TZPPN glass doped with 1-mol% Er³⁺ ions hold promise as an optical material for broadband amplification in the third telecommunications window as well as for generating green light in color display devices.

In conclusion, this feature issue of *Optical Materials Express* offers a timely topical and highly interesting overview of the state-of-the-art in recent advances in a broad range of non-emissive and emissive, organic and inorganic optical materials for display applications. It provides many opportunities for future endeavors in this field. The field spans the entire spectrum from fundamental and novel optical materials characterization to cell fabrication and device performance research for photonic display applications.

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