ADVANCED OPTICAL MATERIALS
www.advopticalmat.de

Light-Responsive Smart Soft Matter Technologies

Quan Li, Albert P. H. J. Schenning,* and Timothy J. Bunning**

Elegant natural phenomena triggered by light are widespread in our everyday environment. Human vision is enabled by such a light-driven process, i.e., photoisomerization of retinal. Phototropic and heliotropic motions in plants (e.g., sunflowers pivoting their faces to follow the sun) are driven by photoisomerization of phytochromes. These light-triggered processes occurring in nature have served as great inspiration for scientists and engineers and as a consequence, a variety of light-responsive functional materials and systems have been explored both scientifically and evaluated for potential in a wide range of technological applications. Soft materials, including liquid crystals, polymers, gels, and biological materials, endowed with photoresponsiveness have recently emerged as multifunctional advanced optical materials for diverse applications. The great interest in such systems arises from their unique combination of contactless energy delivery with the ability to modulate at high spatial and temporal resolution. The explosion of low-cost light sources with tunable wavelength/frequency, intensity and chirality has enabled a new toolbox of stimulus variables. The dynamic attributes of these soft materials have been exploited in the fabrication of photoswitchable and reconfigurable materials and systems with programmable properties and functions. This has enabled the development of a variety of new light-driven soft matter technologies involving molecular switches/motors, shape morphing materials, alignment methods *etc*. The applications of such technologies range from simple on-off switching to sophisticated soft robotics and 3D & 4D printing. In this special issue, significant recent developments of various light-driven phenomena and their applications in soft material systems are covered. A wide range of topics that convincingly illustrate the richness of this vibrant research field are presented by leading experts.

Optical control over bio-interfaces with the help of azo-dye containing soft materials is a promising approach in cell biology and tissue engineering. In their article, Christopher J. Barrett and co-workers (DOI:10.1002/adom.201900091) present various developments on the use of photo-reversible azo-based soft materials in this context. They describe using light to control molecular motion of photoactuating surfaces and patterns for bio-interface applications. Modulation is enabled by light-driven photoorientation, topological patterning, and photomechanical actuation.

Stefano Palagi and co-workers (DOI:10.1002/adom.201900370) discuss wirelessly powering and controlling mobile microscale devices and microrobots using light as a versatile stimulus. They have analyzed the behaviors of two interesting classes of stimuli-responsive polymeric materials, i.e., poly(*N*-isopropylacrylamide) hydrogels and liquid crystal elastomers, in microrobotics and highlighted their recent applications. They also emphasize the significance of a structured light field in driving soft microrobots fabricated from light-responsive polymeric materials.

2D materials are known to exhibit exceptional physical and chemical properties which qualify them as candidates for modern technological applications. Paolo Samorì and co-workers (DOI:10.1002/adom.201900286) report on the functionalization of 2D materials with light-responsive molecules. They discuss functional hybrid systems possessing tunable optical properties and their applications in photoswitchable electronic devices.

Supramolecular polymers exhibit certain distinct characteristics when compared to their synthetic and biopolymer counterparts where the monomers are covalently linked. Da-Hui Qu, He Tian and co-worker (DOI:10.1002/adom.201900033) summarize new developments in light-responsive supramolecular polymers capable of exhibiting novel functions and applications beyond disassembly and reassembly. They discuss light controlled morphology transformations including programmed shape memory and switchable self-healing, muscle-like actuation, and phototunable luminescence.

Innovative soft materials for improved diagnostics and therapeutic applications are currently being actively designed and developed. In their review article, Paula M. Mendes and co-workers (DOI:10.1002/adom.201900215) discuss the design and fabrication of light-responsive materials and systems for biomedical applications ranging from tissue engineering to drug delivery. They highlight certain key strategies tailored to address specific issues in this rapidly growing research area.

3D manufacturing of devices using polymeric materials for light manipulation at the nanoscale is an attractive research area in photonics. Direct laser writing is such a fabrication technique that enables the development of devices with nanoscale precision. Sara Nocentini, Daniele Martella, Diederik S. Wiersma and co-worker (DOI:10.1002/adom.201900156) describe the recent developments in the field of light tunable photonics based on 3D printed polymeric materials. They discuss

Prof. Q. Li
Advanced Materials and Liquid Crystal Institute and
Chemical Physics Interdisciplinary Program
Kent State University
Kent, Ohio 44242, USA
E-mail: qli1@kent.edu

Prof. A. P. H. J. Schenning
Laboratory of Stimuli-responsive Functional Materials
and Devices (SFD)
Department Chemical Engineering & Chemistry
Eindhoven University of Technology
Eindhoven, The Netherlands
E-mail: A.P.H.J.Schenning@tue.nl

Dr. T. J. Bunning
Materials and Manufacturing Directorate
Air Force Research Laboratory
Wright-Patterson AFB, Ohio 45433, USA
E-mail: timothy.bunning@us.af.mil

DOI: 10.1002/adom.201901160

Quan Li is Director of Organic Synthesis and Advanced Materials Laboratory at the Advanced Materials and Liquid Crystal Institute of Kent State University, where he is also Adjunct Professor in the Chemical Physics Interdisciplinary Program. He received his Ph.D. in Organic Chemistry from the Chinese Academy of Sciences (CAS) in Shanghai, where he was promoted to the youngest Full Professor of Organic Chemistry and Medicinal Chemistry in February 1998. He is Fellow of the Royal Society of Chemistry and has been elected as a member of the European Academy of Sciences. He has also been honored as Guest Professor and Chair Professor at several universities. His current research interest spans from stimuli-responsive smart soft matter, advanced photonic and optoelectronic materials for energy-harvesting and energy-saving, and functional biocompatible materials and nanoparticles to nanoengineering and device fabrications.

Albert P. H. J. Schenning studied chemistry at Radboud University Nijmegen, The Netherlands, where he obtained his doctorate in 1996. His PhD thesis on supramolecular architectures based on porphyrin and receptor molecules was supervised by Dr. Martin Feiters and Prof. Roeland Nolte. In 1996, Schenning was a post-doctoral fellow in the group of Prof. Bert Meijer at Eindhoven University of Technology (TU/e), The Netherlands, working on dendrimers. In 1997, he investigated π-conjugated oligomers and polymers based on triacetylenes with Prof. François Diederich at the ETH in Zurich, Switzerland. From 1998 until 2003, Schenning was a fellow of the Royal Netherlands Academy of Arts and Sciences (KNAW) at the TU/e, active in the field of supramolecular organization of π-conjugated systems. In 2010, he changed his research direction and currently he leads the research group Stimuli-responsive Functional materials and Devices at the TU/e.

Timothy J. Bunning is the Chief Scientist of the Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson Air Force Base. Scientifically, he is active in a diverse internal and external R&D effort that is developing new soft matter-based responsive materials and approaches for integration in a variety of applications. His research interests center on responsive optical, electro-optical, and photooptical structured organic materials for utility in optical sensing, laser beam control, and filtering (modulation) applications. Current research areas include the development of 1D, 2D, and 3D switchable polymeric diffractive structures using complex holographic photopolymerization techniques, photosensitive cholesteric/polymer liquid crystal mixtures, photomechanical materials based on photosensitive liquid crystalline networks, novel electro-optic liquid crystal/polymer materials, the development of complex optical stacks using plasma vapor deposited polymeric heterocyclic thin films, and nanostructured optical materials.

direct laser writing patterning of light-responsive materials and their applications in dynamic photonic devices and photonic circuits.

Danqing Liu (DOI:10.1002/adom.201900255) summarizes recent developments of dynamic surface topographies based on light-responsive liquid crystal networks. The reversible transformation of surfaces between smooth and corrugated topographies activated by light irradiation is discussed. This article illustrates the interaction between such dynamic surfaces and the environment leading to controlled friction surface wettability and mass transport, both controlled by light stimulus.

Adhesives capable of on-demand bonding and debonding are attracting growing interest due to their significant functionality in temporal fixation, repair and recycling. Christoph Weder and co-worker (DOI:10.1002/adom.201900230) present recent research activities in the development of photoswitchable adhesive materials. They highlight reversible debonding in adhesives enabled by different optical processes. Emphasis is placed on approaches involving photoisomerizable and photodegradable groups as well as dynamic covalent bonds triggered by either photochemical or photothermal processes.

Light-driven liquid crystalline hierarchical architectures and their photonic applications are covered by Yan-Qing Lu and co-workers (DOI:10.1002/adom.201900393). They discuss special characteristics of cholesteric liquid crystals and blue phases and how they have been judiciously exploited for advanced photonic applications with impressive performances.

Massimo Baroncini, Alberto Credi and co-workers (DOI:10.1002/adom.201900392) highlight through illustrative examples certain basic aspects of light-induced processes in supramolecular architectures. They discuss how the novel functionalities of light-responsive supramolecular architectures can be implemented in the development of smart nanostructured materials and systems for technological applications.

Development of multifunctional molecular photoswitches is necessary toward the realization of light-responsive smart soft matter technologies. In their contribution, Stefan Hecht and co-worker (DOI:10.1002/adom.201900404) outline several molecular design principles and effective implementation of beneficial photoswitching properties in the fabrication of bulk materials. They highlight the use of commonly encountered photoswitches in actuating and self-healing materials and their applications in microfluidic and optoelectronic devices.

Toru Ube and Tomiki Ikeda (DOI:10.1002/adom.201900380) present liquid crystalline polymer-based photomobile materials. They highlight the structure-function relationship in photomobile polymeric materials. Recent progress on the photomobility of these functional soft materials in terms of complex 3D deformations, continuous motions and self-regulation is discussed in detail.

Multiaddressable photochromic architectures have been designed for applications ranging from molecular machines to smart materials. Ryan C. Hayward, Javier Read de Alaniz and co-workers (DOI:10.1002/adom.201900224) highlight recent advances in the design of photo-/chemical-addressable systems, with an emphasis on photo-/pH-addressable, photo-/redox-addressable, and multi-photonic addressable architectures.

Stimuli-responsive polymer membranes where physicochemical properties can be tuned easily are attracting attention for numerous applications. Fiore Pasquale Nicoletta and co-workers (DOI:10.1002/adom.201900252) discuss recent progress on light-responsive polymer membranes, focusing on the nature of the chemical groups and the responsive mechanisms.

Luminous molecular liquids are a distinct class of soft condensed matter which are nonvolatile fluids that emit high intensity homogeneous light and could find potential application in flexible devices. Takashi Nakanishi and co-worker (DOI:10.1002/adom.201900176) outline the latest developments of luminous molecular liquids covering molecular design principles, enrichment and tuning of their photophysical properties, and their emerging device applications.

Soft actuators based on liquid crystalline cross-linked networks have enabled many applications. Yue Zhao and co-workers (DOI:10.1002/adom.201900262) review liquid crystal polymer network based actuators that can be driven by light. They highlight the use of a light stimulus not only as the source of energy to drive shape changes or motion but also as an enabling tool for the fabrication and reconfiguration of liquid crystal network based actuators.

Seungwoo Lee and co-workers (DOI:10.1002/adom.201900074) discuss how soft mass migrations induced by spatially controlled photoisomerization and photopolymerization provide tools for the optical engineering of various microscale and nanoscale photonic devices not readily accessible by conventional lithographic and self-assembly techniques. They summarize recent technological advances on the application of soft mass migration in diffractive optical elements, bioinspired optics, colorimetric sensors, and plasmonic devices.

Shape-changing polymers are regarded as a class of smart stimuli-responsive soft materials. Leonid Ionov and co-workers (DOI:10.1002/adom.201900067) outline recent advancements in the field of light-responsive shape-changing polymers and their applications as light-driven actuators. They classify systems according to the type of materials and their photoactuation and shape-changing mechanism.

Carbon-based materials have been intensely investigated and their combination with soft materials has enabled a range of technologies. Dingshan Yu and co-workers (DOI:10.1002/adom.201900069) review the recent progress of light-responsive actuators built from various carbon-based soft materials involving 0D, 1D, 2D and 3D nanocarbons. They describe photothermal, photomechanical, photoelectronic and photochemical driving schemes in the design of light-responsive actuators containing carbon nanomaterials.

Although liquid crystals are commonly known for their technological application in flat panel displays, they are finding increasing use in beyond-display applications. Michael E. McConney and co-workers (DOI:10.1002/adom.201900429) present recent progress on liquid crystalline systems exhibiting light-responsive structural color. They emphasize liquid crystalline materials and structures where coloration is a consequence of the spatial arrangement of the constituents which can be controlled externally using light as the stimulus. Moreover, they highlight true self-regulation of light flow in liquid crystal systems.

Polymeric structures with well-defined spatial features possessing different shapes, sizes and dimensions, and exhibiting different functionalities are in demand in various fields including microelectronics, biotechnology, tissue engineering, and photonics. Carlos Sánchez-Somolinos and co-worker (DOI:10.1002/adom.201900598) give an overview of structuring of polymeric materials through physicochemical processes using light as the stimulus. They discuss various photochemical reactions in polymers, photosensitive materials, and structuring techniques that span from photolithography to 4D printing.

We hope that this collection of articles sparks further interest in light-responsive functional soft materials and their technological applications. We sincerely thank all the authors for their dedicated and excellent contributions without which this issue would not have been possible. We greatly appreciate the entire editorial team of *Advanced Optical Materials* for their assistance in preparing this special issue. Special thanks to Jos Lenders, Anja Wecker and Heike Höpcke for their valuable support.