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Editorial

Smart shape changing and shape morphing polymeric materials

Smart materials by their very definition are those that are able in some manner to assess their surroundings and respond in an appropriate manner. Numerous materials have been developed based on this paradigm for use in sensors, drug delivery devices, microelectronics and numerous other applications. In the current environment where custom designed and tailorable material properties are critical, polymeric materials represent the most exciting class of these smart materials and the one with the greatest potential for longterm impact. Within the class of smart polymeric materials, a great focus has been placed on polymers that have an ability to change their shape and/or size in response to the application of an external stimulus. The applied external stimulus used to cause the shape change is often temperature but several other stimuli have also been used including magnetic fields, light, the presence (or absence) of a target compound, and the action of cells or enzymatic reactions.

Broadly, there are at least two general types of shape changing and shape morphing polymeric materials: (i) shape memory materials in which a permanent shape is "programmed" into a material, generally during its formation, and transient or temporary shapes are often kinetically trapped within a material, and (ii) shape morphing materials in which the shape of the material is permanently altered by exposure to the desired stimulus, sometimes with the potential for creating a new, arbitrary permanent shape. With this powerful capability for changing shape, these polymeric materials have a wide range of potential applications in numerous critical fields – for example, in biomedical devices such as suture anchors, artificial muscles, and biosensors; optical materials including rewritable holograms and tunable waveguides; and in the areas of microfluidics and microelectronics where shape changes and actuation are used to cause flow, complete circuits and even enable smart robotics. In particular, there has been a recent emphasis by the National Science Foundation and others to identify approaches for interfacing the science of origami with materials design, synthesis and implementation, and it is clear that smart, shape changing polymer materials will be at the heart of many developments within this area.

The special issue encompassed here highlights several novel areas and approaches to shape memory and shape morphing materials. The issue begins with a review [1] that focuses on methodologies for synthesizing new shape memory polymers (SMPs). Given the need for novel material capabilities, it is clear that one necessary aspect of their development will incorporate new synthetic chemistry methodologies for creating these materials. The review [1], focusing primarily on SMPs, highlights various synthetic approaches that have been used both to create and to modify materials to enhance their stability, responsiveness, tunability, and to enable responsiveness to a variety of stimuli. One example of a new chemistry developed for SMPs is the use of cyanate-based polymers modified with polybutadiene–acrylonitrile that leads to a high glass transition temperature suitable for applications in aerospace [2]. A second example of the use of a new chemistry for shape memory materials is also highlighted [3] where the copper-catalyzed azide-alkyne (CuAAC) reaction is used to form crosslinked polymeric materials that have several desirable attributes as SMPs.

A second review by Broer and coworkers on liquid crystalline (LC) polymer networks, one of the most exciting materials used to form shape changing polymer materials, is also included [4]. This review nicely addresses the capabilities of LC materials, summarizes the literature and describes the many approaches through which LCs, their alignment and phase changes are useful in devices and in controlling the overall material shape and its dynamics. Mather and coworkers [5] utilized hydrosilation chemistry for the formation of main chain LC elastomers which were subsequently used in reversible deformation by using both the glass transition and isotropization temperatures.

Hayward and coworkers [6] cleverly used edge effects and defects arising during the formation of hydrogels to cause localized buckling of an otherwise flat sheet. They demonstrated that the radius of curvature of the structure could be controlled by several factors including the degree of swelling and the initial geometry of the film. Rather than using swelling to actuate materials, White and coworkers [7] utilized the isomerization of azobenzene to actuate crosslinked polyimides, forming photoactivated wireless actuators. Additionally, light can be used to cause numerous other actuation and shape change behaviors. Theoretical calculations for the oscillatory Belousov–Zhabotinsky (BZ) reaction, which can be modulated with light, indicate that clusters of BZ reactive gels can be coordinated and activated by light exposure to do useful rotation and work [8].

Several distinctive processes for activating, controlling and understanding shape change are also incorporated into this special issue. For example, polymer networks incorporating addition-fragmentation-chain transfer capable moieties enable an otherwise permanently crosslinked network to be reprogrammed with rewritable nanoscale surface patterns using nanoimprint lithography [9]. Fundamental analysis of acrylate-carbon black filled composites [10] indicates that there are significant strain-history effects on the shape memory performance, softening and recovery characteristics. Demonstrating how simple it can be to program the bulk shape in shape memory polymers, Dickey and coworkers [11] illustrate that judicious selection of the cutting direction in a film relative to the initial strain direction is useful in forming complex shapes and patterns in materials. Lendlein and coworkers [12] found that magnetic-field activated SMP behavior could be

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controlled by the covalent inclusion of magnetite nanoparticles into the polymer matrix.

Numerous articles within this issue also explore the implementation of shape changing materials in various applications. In an exciting implementation of SMPs, Aoyagi and coworkers [13] used the contrast between permanent and temporary surface topographical patterns to examine the time-dependent responsiveness of fibroblast cell alignment to changes in surface morphology. Further, improvements in the processing and performance of 3D printed (i.e., by additive manufacturing) SMP parts are achieved [14] by exposing the printed parts to radiation that induces crosslinking, ultimately enabling enhanced SMP capabilities to be achieved from the rapidly evolving practice of using 3D printing for polymer fabrication.

The critical need for simple, robust shape changing materials that respond rapidly, repeatedly and reliably to an applied stimulus demands that significant efforts and improvements are made in the materials and approaches currently used. Comprehensively, outcomes will be achieved in the areas of new approaches to the chemistry of these materials, new processing methodologies, improved implementations of current approaches, and creative combinations of all of these. This special issue highlights work at the frontier of these areas and lays the groundwork for continued development and enhancements in this area.

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