University of Fribourg / Faculty of Science and Medicine / Department of Chemistry

Mechanically morphing polymer systems

Livius F. Muff

Soft robots that are deformable, flexible, and resilient rely on or would benefit from soft actuators to generate (loco)motion and force to interact with objects and their surroundings. Bilayer actuators are composed of two distinct layers that undergo dissimilar anisotropic volumetric expansion in response to an external stimulus, such as heat. To maximize the bilayer deflection and thus increase the actuator efficiency, a high-thermal-expansion material, typically a rubbery or semicrystalline polymer, is combined with a low-thermal-expansion layer, such as a glassy polymer. However, the large discontinuous thermal expansion associated with the melt transition of semicrystalline polymers cannot readily be used for bilayer bending actuators because they liquefy above the melt temperature, and this compromises the bilayer's mechanical integrity. The work presented in this thesis shows that this limitation can be overcome by using a segmented polyurethane elastomer featuring a crystallizable soft segment and hard segments that serve as physical cross-links and provide the necessary mechanical strength above the melting temperature of the crystalline domains formed by the soft segments. We demonstrated that a polyurethane elastomer with a crystallizable polyester soft segment can be used to exploit the melt transition for higher thermal expansion. Bilayer bending actuators based on this material were operated at convenient temperatures and in a narrow temperature range. The merit of this material for soft robotics was demonstrated with the construction of a grabbing arm capable of picking up, moving, and dropping an object. We further improved the actuation-relevant material properties, i.e., crystallinity and thermal expansion, by replacing the polyester soft segment with a highly crystalline polyether. Bilayer bending actuators fabricated from this material were used to construct a four-legged walker capable of multi-directional locomotion and a six-segmented worm robot with the striking ability to wriggle itself through confined spaces smaller than its minor resting diameter.

Overall, the studies conducted on polyurethane elastomers within the framework of this thesis contributed to the emergence of a new class of high-thermal-expansion materials that were integrated into both existing and new soft robotic designs. The findings have implications for the next generation of high-thermal-expansion materials as well as for the efficient integration of these materials into soft actuators for soft robotic systems.

Evaluation committee:
Prof. Dr. Christoph Weder (thesis director and supervisor)
Dr. José A. Berrocal (internal examiner)
Dr. Dorina M. Opris (external examiner)
Prof. Dr. Ullrich Steiner (president of the jury)