Macro-, Micro- and Nano-Actuators Based on Liquid Crystal Elastomers – a bottom-up molecular design

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Artificial muscles are man-made materials that try to reproduce the two main characteristics of real muscle fibers, namely, elasticity and contractility. They respond to various external stimulations (ion concentration, electric field, temperature, light etc.) by a significant shape or size change. In addition to classical materials such as piezoelectric ceramics and shape memory alloys, polymer-based artificial muscles have become the most important muscle-like materials since the 1990s [1]. They offer operational similarity to biological muscles in response to external stimulation. They are resilient and damage tolerant and they exhibit large actuation strains (stretching, contraction, or bending). Artificial muscle systems have many potential applications of great interest, including serving as the materials foundation for fabrication of sensors, microrobots, micropumps, and actuators with combinations of size, weight, and performance parameters beyond those currently achievable.

In this talk, we discuss one particular kind of polymer-based artificial muscles, the nematic liquid crystal (LC) elastomers. LC elastomers combine the properties of LC systems with orientational ordering and those of polymer networks with rubbery elasticity [2]. LC elastomers as artificial muscles were first proposed by P.-G. de Gennes [3–4]. We present here a bottom-up strategy to make artificial muscles, using nematic side-chain and main-chain LC polymers as building blocks. The overall material response in these artificial muscles reflects the individual macromolecular response: the contraction/elongation of the material results from the individual macromolecular chain shape change, from stretched to spherical at the nematic to isotropic phase transition triggered by external stimuli [5-6]. This approach is particularly interesting for the development of micro- and nano-sized actuators.

We discuss first the macroscopic LC elastomers-made actuators whose size is in the millimetre/centimetre range. They are thermo-responsive or photo-responsive: 20-45% of reversible contractions are obtained upon temperature change or UV illumination [7-9]. Then, micrometer-sized actuators with various shapes prepared using soft lithography are demonstrated [10-11]. In the example of responsive surfaces composed of cylindrical or square micrometer-sized nematic main-chain LC elastomer pillars, the individual pillars behave as micro-actuators, showing ultra-large and reversible contractions of around 300-400% at the nematic to isotropic phase transition [12]. At the end, we use the approach of amphiphilic block copolymer self-assembly to prepare nanometer-sized actuator. This nano-actuator is a 10nm-thick bimorph with only one photo-responsive layer, which closes up to constitute the bilayer membrane of a spherical polymersomes (polymer vesicles). The photo-actuation of the membrane creates a spontaneous curvature in the membrane and results in instantaneous polymersomes bursting [13]. The versatility of this actuator mechanism should broaden the range of applications of polymersomes in fields such as drug delivery, cosmetics and material chemistry.

References:
6. (a) Li, M.-H., Brulet, A., Davidson, P., Keller, P., Cotton, J.-P., Observation of hairpin defects


