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Shape-Memory Elastomers for Soft Actuators: Challenges and Opportunities

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ABSTRACT

Shape-memory elastomers (SMEs) have emerged as promising smart-materials platforms for soft actuators and intelligent structures due to their programmable thermally-induced reversible shape transformations. However, four critical scientific and technological challenges impede their practical engineering implementation. First, the thermodynamic and molecular mechanisms governing their thermomechanical behavior remain incompletely elucidated. Second, achieving large reversible deformations requires retention of molecular orientation during thermal actuation cycles- a persistent challenge given their large strain recovery at the heating temperature. Third, while biological muscles achieve sub-second actuation, current SME systems exhibit response times spanning several seconds, necessitating at least one order of magnitude reduction in response time. Fourth, integrating electrothermal heating elements essential for practical applications often degrade actuation performance. This work presents a critical analysis of these challenges through the lens of developing next-generation SME actuators combining short response time ($\leqslant$500 ms), large reversible strains (>20%), and embedded electrothermal functionality. Furthermore, promising research directions in the development and application of SME actuators are identified.

KEYWORDS

Smart materials; intelligent structures; shape-memory elastomer; soft actuator

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