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Li alloy-based non-volatile actuators

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ABSTRACT

Conventional artificial muscles induce bending by aligning large-sized ions within the electrolyte upon bias application. Such design, alike many other actuator types, suffer from volatile actuation where the actuated position gets lost upon switch-off. Here, we develop a non-volatile artificial muscle with ion insertion electrode materials. Upon bias application, the inserted ions pose stress on the electrodes that sustain even after power shut-off. The demonstrated actuator consists of lithium germanide (Li_xGe) thin films deposited on both sides of a flexible polyimide (PI) substrate. The device exhibits 35.2 mm displacement when operated at 2 V and generates the blocking force of 0.67 mN. The observed stress and volume expansion reach 248 MPa and 8.2% for the 284 nm Li_3Ge thin films, respectively. The actuated position is maintained against gravity with 12.1% decay in the actuated distance after 10 min. The novel actuator type proves the potential use of lithium insertion materials as actuation materials and shows that non-volatile actuation can be realized with ion-insertion electrodes.

1. Introduction

Actuators form the basis of the modern robotics industry, with applications ranging from microelectromechanical devices to medical or consumer electronics [1–4]. Various actuator types including piezoelectric actuators [5], shape memory alloys [6,7] and electrochemical actuators [8–10] have been devised to meet the wide range of application needs. Especially, recent urge to develop humanoid robots [11] or biomimetic soft robots [12,13] call for further development of a special kind of actuators called the artificial muscles [14,15].

The requirements for successful artificial muscles include a large amount of strain (~ 10%) and stress above 1 MPa, preferably with low power consumption [2]. Several novel actuator types have been suggested to serve as artificial muscles such as the single-ion conducting polymer-based actuators [16] or electrochemical actuators [8]. These actuators achieve successful integration into several robotics parts, with the characteristically large amount of strain, fast response time and below 1 V operation. Successful demonstrations include over 1% strain at 1 V or lifting weight 150 times the actuator weight.

For artificial muscles, low power consumption not only means the low operation voltage but also non-volatile actuation where the actuator maintains its position even after the electrical power has been turned off. Most artificial muscles developed so far, however, feature volatile actuation where voltage must be continuously supplied to maintain the actuated position; as soon as the input voltage is turned off, regardless of how big or small the operation voltage, the actuated position returns to its original position [16]. Such volatile actuation is featured in most well-known actuators, including the piezoelectric, shape memory alloy-based, electrostrictive and ionic actuators [5,7,17]. For artificial muscles, this volatility indicates a significant loss of efficiency, as mimicking human motions involve a series of constant actuated positions. The design of non-volatile actuation may significantly improve on the power efficiency of artificial muscles, yet such capability has not been devised with many well-known artificial muscles.

Here, we develop and demonstrate a non-volatile artificial muscle via lithium (Li) insertion-based electrochemical actuators. The device consists of Li_xGe thin film electrodes on both sides of the PI substrates. When the driving voltage is supplied, Li migrates from one side to the other, inducing chemical strain. The in-plane stress generated by accommodating additional Li bends the actuator. Since the composition change during operation is maintained even after the power shut-off,

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