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Towards Solid-State Actuation Using Electrochemical Storage Compounds

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Prospects for an actuation technology based on the electric field driven intercalation (ion-exchange) of high-modulus inorganic compounds will be discussed. Such compounds are exemplified by lithium transition metal oxide cathodes (e.g., $LiCoO_2$, $LiMn_2O_4$, $LiFePO_4$) and carbon anodes heretofore developed as storage electrodes for rechargeable battery systems, which can be intercalated with Li^+ ions at low voltages of 1.5-5V to large and reversible volume changes of typically 3-13%. In this talk, we will discuss materials systems and device constructions that can utilize the electrochemically-induced strain for actuation. The fact that many such intercalation compounds have high elastic modulus (50-150 GPa) suggests that large actuation authority as well as large free strain may be possible. The low operating voltages are attractive, while the resulting electrochemical driving forces are sufficiently large (1.5-5 eV per atom) that stresses up to and even beyond the intrinsic compressive strength of the materials should be possible. In addition, these compounds have low densities (3.5-5 g/cm^3) compared to lead-based piezoelectrics or metal alloys comprising magnetostrictors and shape memory alloys, and result in impressive projected actuation figures of merit.

Projected actuation energy density using known materials is close to that of hydraulic actuators, and improvements in the choice of materials could produce significantly higher energy densities. The potential exists for the development of a new class of high-strain, high-authority, moderate-frequency actuators suitable for a broad range of applications, including nastic structures utilizing a distributed system of small actuators. Results will be presented for simple layered devices that demonstrate the potential, and highlight research and development needs, in these novel devices.