

From Electrometallurgy to Liquid Metal Battery for Grid-energy Storage

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Abstract:

Low-cost and scalable battery is an enabler for grid-energy storage applications. Inspired by the large-scale electrolysis cell for liquid metal production, the invention of liquid metal battery (LMB) is deemed as a suitable technology for tackling large-scale energy storage issues in terms of the cost, scalability, and the capacity retention. The first generation of liquid metal battery consisted of three liquid layers, i.e. a molten-salt electrolyte is sandwiched between two liquid metal electrodes, a dense positive electrode lies at the bottom of the battery, while a low-density negative electrode floats atop the electrolyte. The difference in composition between the two liquid metals gives rise to a voltage. However, the voltage of the first-generation liquid metal battery is below 1V. In order to increase the cell voltage, a liquid metal displacement chemistry was employed to substitute the alloy-dealloy positive electrode in the first generation of LMBs. To make this chemistry work efficiently, a brand-new ion selective membrane was required. In a radical departure from the classical ceramic conductor which achieves chemical selectivity by regulated ionic conduction, i.e., only one designated ion can be transported. Herein, we disclose a new porous electronically conductive membrane, which achieves chemical selectivity by preferred faradaic reaction instead of by regulated ionic conduction, i.e., discharge (by electron transfer) of ions differentiated on the basis of their relative electrochemical reactivities. This shift in membrane mechanism grants access to a variety of heretofore forbidden choices for positive and negative electrode metals and allows the battery to charge and discharge at high rate without degradation in performance. Fitted with a porous membrane of TiN, a displacement cell comprising a liquid Pb positive electrode, a liquid Li Pb negative electrode, and a molten salt electrolyte of PbCl₂ dissolved in LiCl-KCl eutectic was cycled at a current density of 150 mA cm⁻² at a temperature of 410°C and exhibited a coulombic efficiency of 92% and round-trip energy efficiency of 71%. The rate of capacity fade due to permeation of Pb ion through the membrane was measured to be 0.00172% per cycle, which is tantamount to retention of greater than 94% of initial capacity after 10 years of daily cycling. Most significant from the standpoint of industrial scalability, we show that the faradaic membrane can be fashioned out of metal so as to be mechanically durable and therefore easily mass-produced without regard to its size-to-thickness ratio.