



capacities. A carefully designed electrolyte that used an organic lithium salt, a blend of three organic solvents, and novel stabilizing agents acted as an essential partner to this electrode and ensured its durability over thousands of charge and discharge cycles. This stable system delivered a 795-Wh/L stack energy density and performed at high efficiencies over 3700 cycles at 20°C and 40°C. The unique design of the cathode ensured that the electrodes never cracked or effused active material.

Georgia Institute of Technology professor Gleb Yushin, who is unaffiliated with this research effort, assessed the impact of the work: “Development of longer lasting batteries [is] critical for

both autonomous electric mobility and clean energy grid. Revealing key contributions to cell degradation, as demonstrated by this excellent work and others, enable materials scientists to fine-tune both electrode particles and electrolytes to overcome the current Li-ion limitations. In the near future, I expect new anode and cathode chemistries beyond graphite and NMC [nickel manganese cobalt] will push the limits of energy density versus cycle life to new heights.”

The researchers validated the longevity of their cells against comparable commercial cells and replicated expected operating conditions. The team stored the cells in temperature-controlled ovens for over a year and periodically

cycled them to assess their thermal stabilities. Battery testing cycled the energy-storage modules at different rates and combined electrochemistry information with changes in volume (due to aging-induced generation of gas in the cells) and characterization of electrodes at different time points. The researchers meticulously documented their test methods and ensured that researchers could easily replicate these results or build upon them in follow-up efforts. Many of the tested cells are—to this day—still cycling in the Dalhousie University laboratories, and readers are encouraged to contact the research team and inquire about the current operating status.

Boris Dyatkin

ENERGY FOCUS

Metal-organic-framework-derived “sandwiches” enhance longevity of Li-S batteries

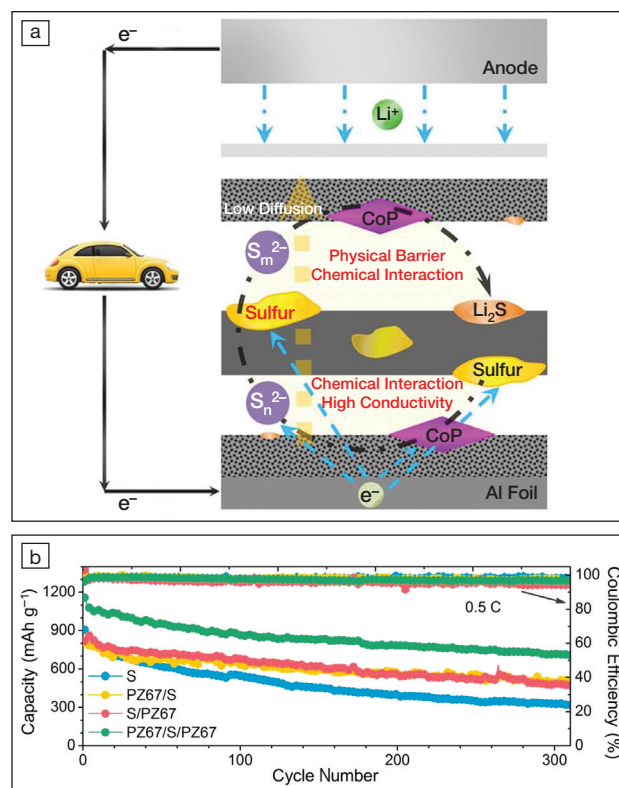
Rechargeable lithium-sulfur (Li-S) batteries with elemental sulfur and lithium metal as cathode and anode, respectively, are promising electrochemical energy-storage devices with energy densities 3–5 times higher than those of rechargeable Li-ion batteries. However, the practicality of Li-S batteries is significantly compromised by their short lifetimes that are mainly associated with polysulfides, the intermediate products formed during cycling. Once formed, these electrolyte-soluble species diffuse to the Li metal anodes and deposit as Li_2S on the Li surface. The deposition passivates Li and reduces the concentration of Li^+ available for electricity storage. Therefore, developing methods to prevent polysulfide diffusion to Li anodes is crucial for addressing the implementation challenge for the Li-S battery.

In *APL Materials* (doi:10.1063/1.5122819), Bo Wang and co-workers of the Beijing Institute of Technology, China, describe a cobalt phosphide/porous carbon composite (PZ67) that prevents the leaking of polysulfides into the electrolyte. The PZ67 composite results in Li-S batteries with a high capacity (a metric for quantifying electricity-storage

capability) that goes beyond 300 charge-discharge cycles.

According to the first author, Xing Gao, the purpose of this work was to utilize polar compounds and porous carbon networks to trap polysulfides. To realize this goal, the researchers selected ZIF-67, a type of cobalt-containing metal-organic framework (MOF), as a starting material. MOFs are crystalline coordination compounds consisting of metal ions or clusters and organic ligands. Through thermal annealing and phosphidation by NaH_2PO_4 under N_2 atmosphere, ZIF-67 was converted to cobalt phosphide (CoP) nanoparticles wrapped with N-doped mesoporous carbon matrices.

The PZ67 composite functioned as a “cage” to confine polysulfides near



(a) Scheme showing that the PZ67 “sandwich” prevents polysulfides (S_m^{2-} and S_n^{2-}) from diffusing to Li anodes. (b) Cycling stability of Li-S batteries with various cathodes: bare sulfur (S), PZ67-supported sulfur (PZ67/S), PZ67-covered sulfur (S/PZ67), and PZ67-sandwiched sulfur (PZ67/S/PZ67). CoP, cobalt monophosphide. Credit: *APL Materials*.

sulfur. Specifically, sulfur was sandwiched between two pieces of PZ67 but remained accessible to Li^+ through



the mesoporous carbon, and the carbon matrices could transport electrons to sulfur, which ensured the functionality of sulfur. Congruently, polysulfides anchored by the polar CoP nanoparticles and adsorbed in the carbon mesopores were immobile, which prevented the shuttling of polysulfide to Li metal. A Li-S battery with a PZ67-sandwiched sulfur electrode retained a high capacity of 715 mAh g^{-1} (at 0.5 C charge-discharge rate after 300 charge-discharge

cycles), a value appreciably higher than those of bare (330.5 mAh g^{-1}), PZ67-covered (489.2 mAh g^{-1}), and PZ67-supported (481.6 mAh g^{-1}) sulfur cathodes under identical testing conditions.

Wei Luo, a professor in the School of Materials Science and Engineering at Tongji University, China, says that “this work presents an excellent example of the critical role of preparing novel electrode materials or structures in propelling

the development of Li-S chemistry.” Luo was not involved in this work.

The researchers are actively seeking ways to expand the impact of this work. “We want to scale up the fabrication process of the hybrid sulfur electrode using a hot-pressing method,” Gao says. The researchers are also investigating strategies for making Li anodes polysulfide-resistant to boost the lifetimes of Li-S batteries.

Tianyu Liu

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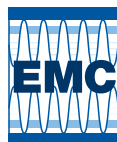
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