

Docket #: S17-207

# Stable Lithium Ion Battery Electrodes via Interfacial Layers

Stanford researchers have developed various high ionic conductivity thin films ( $\text{LiAlO}_2$ ,  $\text{LiAlF}_4$ ) to stabilize lithium ion battery electrodes without sacrificing power density. The atomic layer deposited interfacial layer reduces side reactions between electrolyte and electrode when operated at a wide electrochemical window, maintains power density, and improves energy density - making a safer battery. These thin films are electrochemically inert, chemically stable, lithium ion conductive and can be applied to various battery cathodes.

## Stage of Research

Researchers successfully deposited and tested the interfacial layer on high Ni content, layered lithium transition metal oxides. NMC-811 ( $\text{LiNi}_{0.8}\text{Mn}_{0.1}\text{Co}_{0.1}\text{O}_2$ ), a low cost and high capacity electrode, is often limited to narrower electrochemical windows to maintain long-term stability. The  $\text{LiAlF}_4$  film provided a stable and lithium permeable interfacial layer - stable over 300 cycles with capacity retention higher than 99.9% per cycle at a wide electrochemical window of 2.75-4.50V vs.  $\text{Li}^+/\text{Li}$  with a capacity exceeding 140 mAh/g. The  $\text{LiAlF}_4$  film coated electrode also outperformed uncoated samples at elevated temperatures (50 C) - pristine samples rapidly decayed from 200 mAh/g to less than 100 mAh/g within 100 cycles, while  $\text{LiAlF}_4$  coated samples maintained capacity exceeding 140 mAh/g within 100 cycles.

For further demonstration of ALD films, Stanford researchers deposited chemically inert and ionically conductive  $\text{LiAlO}_2$  on  $\text{LiCoO}_2$  electrodes by atomic layer deposition. The  $\text{LiAlO}_2$  coating prevented reactions between the electrode and electrolyte, while allowing lithium ions to freely diffuse into  $\text{LiCoO}_2$  without sacrificing power density during prolonged high-voltage cycling. The coated electrode's capacity value neared 200 mAh/g for 50 stable cycles with commercial level loading densities (cycled at cut-off potential of 4.6 V vs.  $\text{Li}^+/\text{Li}$ ) - a **40% capacity gain** compared with commercial samples cycled at a cut-off potential of

4.2 V vs. Li+/Li.

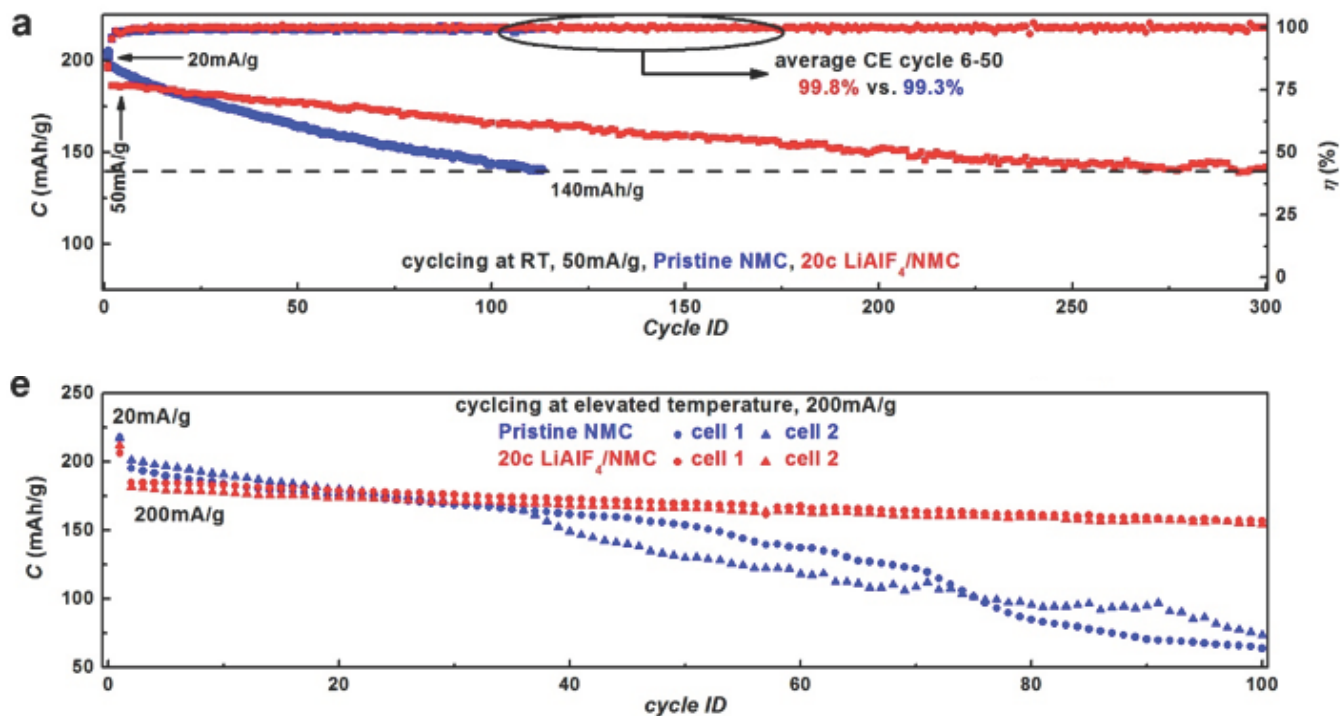


Figure 1. (a) Cycle performance of uncoated (pristine) and LiAlF<sub>4</sub> coated NMC-811 electrodes at room temperature with an electrochemical window of 2.75-4.50V vs. Li+/Li;

(e) Cycle performance of uncoated (pristine) and LiAlF<sub>4</sub> coated NMC-811 electrodes at elevated temperature with an electrochemical window of 2.75-4.50V vs. Li+/Li.

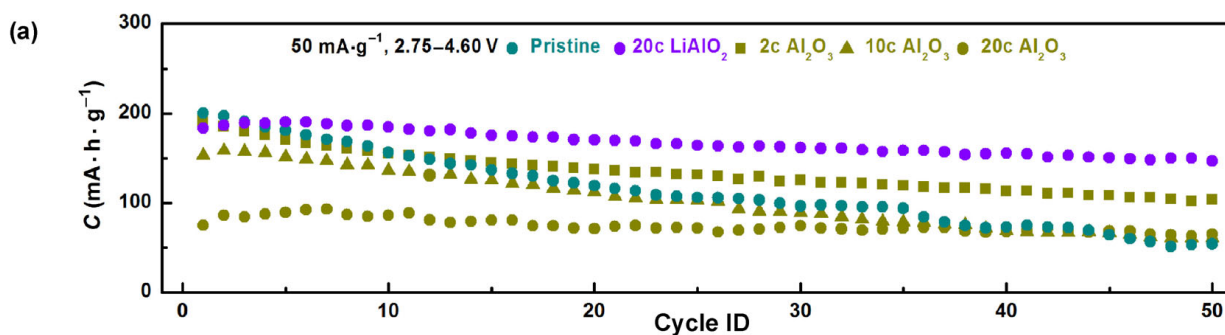


Figure 2. (a) Cycle performance of pristine, 20-cycle-ALD LiAlO<sub>2</sub> coated, and 2-, 10-, 20-cycle-ALD Al<sub>2</sub>O<sub>3</sub> coated LiCoO<sub>2</sub> electrodes

## Applications

- **Lithium ion batteries** like those used in portable electronics, electrical vehicles, and grid scale power.

## Advantages

- Chemically stable, electrochemically inert, lithium ion conductive, and highly uniform cathode.
- Scalable battery production.

## Publications

- Cui, Yi and Jin Xie. "[Atomic layer deposition of stable lithium ion conductive interfacial layer for stable cathode cycling](#)." WO2018222366 A2, World Intellectual Property Organization, Publication Date 2018-12-06.
- Xie, Jin, Austin D. Sendek, Ekin D. Cubuk, Xiaokun Zhang, Zhiyi Lu, Yongji Gong, Tong Wu et al. "[Atomic Layer Deposition of Stable LiAlF<sub>4</sub> Lithium Ion Conductive Interfacial Layer for Stable Cathode Cycling](#)." ACS nano 11, no. 7 (2017): 7019-7027.
- Xie, Jin, Jie Zhao, Yayuan Liu, Haotian Wang, Chong Liu, Tong Wu, Po-Chun Hsu, Dingchang Lin, Yang Jin, and Yi Cui. "[Engineering the surface of LiCoO<sub>2</sub> electrodes using atomic layer deposition for stable high-voltage lithium ion batteries](#)." Nano Research (2017): 1-11.

## Patents

- Published Application: [WO2018222366](#)
- Published Application: [20200152976](#)
- Issued: [11,894,546 \(USA\)](#)

## Innovators

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