INSIGHT SERIES

FROM EXPERTISE TO IMPACT

HyLiST

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Is the integration of LNMO-based cathodes the answer for scalable, sustainable solid-state energy storage?

Abstract

The demand for high-energy-density batteries is increasing as technology advances to meet the needs of applications like aircraft and electric vehicles (EVs), both of which require fast charging and high energy density. Achieving this involves optimizing electrodes for high voltage and capacity. Lithium Nickel Manganese Oxide (LNMO) is a promising cathode material due to its high voltage (4.7 V), which enhances energy density and provides a more sustainable alternative to traditional materials. However, LNMO faces several challenges, including the Jahn-Teller effect, two-phase reactions, oxygen evolution, and material limitations at high voltage. Additionally, the safety of liquid electrolytes commonly used in lithium-ion batteries raises concerns for next-generation battery technologies. HyLiST project focuses on the development of solid-state batteries to address these challenges. One key hurdle is maintaining polymer stability at high voltages, particularly with ionically conductive binders. To overcome this, the project proposes the use of single-ion conductive polymers, which enhance charging speed, reduce polarization, and support sustainability using water or eco-friendly solvents. This blog delves into the challenges of cathode formulation when transitioning from liquid to solid electrolytes in LNMO-based cathodes.

Design of LNMO-based Cathodes for Solid-State Batteries

The urgent need to develop high energy density batteries to meet society's evolving demands is becoming increasingly critical. As technology advances, **batteries are being specifically tailored for diverse applications**, each with distinct performance requirements.

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For example, both aircraft and electric vehicles (EVs) rely on batteries with high energy density and fast charge, yet their operational needs differ significantly. A key distinction lies in power output:

- **Aircraft batteries** must deliver extremely high power during critical phases such as take-off and landing
- **EV batteries**, though requiring adequate power smooth acceleration, prioritize sustained performance over longer durations.

High energy density and fast charging are essential requirements for both sectors, but meeting these demands presents a significant engineering challenge. Achieving high energy density typically involves developing electrodes with high operating voltage and capacity. However, from a sustainability perspective, it is crucial to minimize the use of critical materials such as cobalt.

One promising solution for **achieving high energy density is the use of Lithium Nickel Manganese Oxide (LNMO)** as a cathode material. This active material is considered a stable supply chain which helps to reduce the environmental impact as it consists of nickel and manganese, along with lithium. It is the most sustainable option compared to other cathode materials ($LiNi_xMn_yCo_yO_2$, $LiCoO_2$) that rely on scarce and ethically problematic materials. The high operational voltage of LNMO translates to a higher energy density for the entire battery system. While the high operational voltage (4.7 V) of LNMO provides the advantage of increased energy density, it also presents challenges - including the Jahn-Teller effect, two-phase reaction, oxygen evolution, and the fact that few materials can sustain such high voltage. These issues pose significant material challenges that need to be addressed for improved stability and performance.

When selecting materials for batteries, **safety** is one of the primary considerations. This is especially important in relation to the thermal stability of liquid electrolytes, which is under scrutiny. While polymer electrolytes are generally considered safer than traditional liquid electrolytes, they present challenges when paired with commercially available cathode materials. In solid-state batteries cathode composition used in regular Li-ion batteries needs to be adapted. Polyvinylidene fluoride (PVDF) is commonly used binder in conventional cathodes, which helps to integrate carbon additives and active materials. However, in the case of solid-state batteries, **the binder must also be ionically conductive to ensure efficient ion conductivity**, as the solid polymer electrolyte does not permeate through the cathode as liquid electrolytes do.

The challenge arises as ionically conductive polymers struggle to maintain high voltage stability, which is essential particularly in LNMO based cathodes. To address this issue, the **composition of the catholyte** (ionically conductive binder) must be adapted to meet three critical requirements:

- High voltage stability
- Ionic conductivity
- Binding properties

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This is often achieved by **incorporating additives into the catholyte**, which stabilize the material at high voltages and improve its overall performance. These additives can help to mitigate the degradation of the polymer, ensuring that the battery remains functional over a longer cycle life while maintaining both safety and performance. In HyLiST EU-funded project, **single-ion conductive polymer** has been proposed as the primary components of the catholyte. This polymer will serve a dual purpose, acting as a binder and as a source of lithium ions.

What sets these types of polymers apart is the anion is **covalently bonded to the polymer chain**, effectively immobilizing the anion and ensuring low cell polarization. This design feature significantly contributes to **faster charging and discharging cycles**, as the anion immobilization reduces polarization gradients. The reduction in polarization gradients is particularly beneficial for high-power applications, such as aircraft during take-off and landing, where quick energy delivery is essential, or in applications, which require rapid battery charging. Another key benefit of using a PVDF-free cathode is the range of solvents that can be used. Typically, these materials can be processed with water or more sustainable solvents, contributing to a step forward in sustainability, which is the basis of the HyLiST project.

In summary, **the development of high energy density batteries is essential to meet society's increasing demands**. The HyLiST project focuses on developing safe LNMO-based solid-state batteries for aircraft and EV applications, and, in these batteries, the catholyte will be meticulously designed to ensure high ionic conductivity, strong binding properties, and resistance to degradation during cycling. The project aims to utilize single-ion conductive polymers as catholytes, which will enable faster charging, improved stability, and enhanced sustainability by using water or eco-friendly solvents.

About the author

Leire Meabe is an Ikerbasque Research Fellow and Senior Researcher at CIC energiGUNE. She earned her Ph.D. in 2019 in Applied Chemistry and Polymeric Materials through a joint program between the University of the Basque Country (POLYMAT) and the Université de Pau et des Pays de l'Adour, with research stays at Yamagata University in Japan and Deakin University in Australia. Her research expertise focuses on the synthesis and characterization of polymeric materials, specifically polycarbonates and single-ion conducting electrolytes, for next-generation lithium metal and solid-state batteries. Her current work is dedicated to developing advanced polymer electrolytes and engineering stable solid-electrolyte interfaces to enhance the safety and performance of high-energy storage systems. By leveraging polymer chemistry and electrochemistry, her goal is to drive the transition toward more sustainable and efficient energy technologies for the automotive and energy sectors.

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