

# Smart and Functional Materials for Lithium-Ion Battery

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## 1. Introduction

Climate change and energy dependence are nowadays critical issues that the world is facing, requiring effective and urgent actions to properly address them in a timely fashion. These issues are related to a strong dependence on fossil fuels, resulting from the increased mobility of population, industry, and energy consumption. In fact, energy and climate change are included in the United Nations agenda, in goals number 7 and 13 of 17 of the “Objectives for Sustainable Development” until 2030, in the scope of the affordable and clean energy and climate action goals, respectively, demanding efforts to improve decarbonization and the reduction of greenhouse gas emissions.

One of the ways to reduce dependence on fossil energy sources is to increase and promote the use of renewable energy combined with energy storage systems, as has already been adopted by different countries. Lithium-ion batteries represent the most suitable energy storage systems for a wide range of applications, including small electronic devices, smartphones, laptops, electric vehicles, or even home storage systems. However, considering their increasing use and implementation, there is a growing demand for advanced materials to improve battery performance (energy/power density, extended lifetime, conversion efficiency), decrease cost, improve safety, and reduce environmental impact. Some of these advanced materials are based on smart and (multi)functional materials for different battery components (electrodes and separators/solid polymer electrolytes), allowing one to optimize component and interface morphology and physico-chemical processes, as well as to provide additional complementary functions, such as self-sensing and self-healing characteristics. Thus, smart and (multi)functional materials are among the classes of materials with suitable and promising characteristics for the next generation of materials with a specific, tailorable, active, and controllable response to improving battery performance.

In this scope, in the following, we provide a brief account of the review, and research published papers in this Special Issue, divided by materials for electrodes and solid polymer electrolytes.

## 2. A Short Review of the Contributions of This Special Issue

The Special Issue contains a review paper and five research papers on lithium- and sodium-ion batteries.

The review paper [1] provides an overview of the latest advances of materials for lithium-ion batteries. Recent developments and materials for all components (electrodes, separators, solid polymer electrolytes) of lithium-ion batteries are present, together with the future trends in this field. It is also indicated that continued efforts are needed to improve materials, and that advanced materials are required for the new generation of these lithium-ion batteries.

The research papers in this Special Issue include active materials for electrodes and solid-state electrolytes (SSE).



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Carbonaceous materials are widely used for anodes electrodes, and one of the works [2] demonstrates the functionalizing/doping of mesoporous carbon (N-CMK-8) with nitrogen for lithium-ion batteries. This active material shows  $\sim 1000 \text{ mAh}\cdot\text{g}^{-1}$  at  $0.1 \text{ A}\cdot\text{g}^{-1}$  and retains  $\sim 200 \text{ mAh}\cdot\text{g}^{-1}$  at the fast rate of  $5 \text{ A}\cdot\text{g}^{-1}$ . The strategy is highly promising for improving anode performance for the next generation of batteries.

In relation to active materials for cathode electrodes, one contribution is related to  $\text{LiAl}_{0.1}\text{Mn}_{1.9}\text{O}_4$  (LAMO) [3], and another to  $\text{Li}_{1.33}\text{MnTiO}_{4+z}$  ( $0.8\text{LiMnTiO}_4 \bullet 0.2\text{Li}_2\text{Mn}_{0.5}\text{Ti}_{0.5}\text{O}_3$ ) [4].

In order to solve the issues on capacity fading and the Jahn–Teller distortion of spinel  $\text{LiMn}_2\text{O}_4$ , the authors developed a new active material based on  $\text{LiAl}_{0.1}\text{Mn}_{1.9}\text{O}_4$  with a titanium nitride (TiN) coating layer via magnetron sputtering [3]. This new active material has proven to be capable for enhancing the cathode performance in LIBs, the coating layer promoting electron transport to the inner active material.

The contribution from Vu et al. [4] presents the spinel-layered cathode material  $\text{Li}_{1.33}\text{MnTiO}_{4+z}$  synthesized by the sol-gel technique, where the relationships between synthesis temperature, structure, and the electrochemical performance of the cathodes were evaluated. This active material shows a high capacity of 222 and 170  $\text{mAh}\cdot\text{g}^{-1}$  at C/10 and 1C, respectively, and a capacity retention of 90.5% after 100 cycles.

In addition, this Special Issue also presents a research article on active material for sodium ion batteries. The active material is sodium manganite ( $\text{NaMnO}_2$ ) and the work presents experimental and density functional theory calculations [5]. It was demonstrated that the monoclinic phase ( $\alpha\text{-NaMnO}_2$ ) shows better electrochemical reversibility for the sodium intercalation reaction in comparison to the orthorhombic phase ( $\beta\text{-NaMnO}_2$ ).

Finally, considering that thermal issues are strongly relevant for LIBs applications, a world is presented addressing the thermal conductivity for three types of solid state electrolytes (SSE):  $\text{Li}_7\text{La}_3\text{Zr}_2\text{O}_{12}$  (LLZO),  $\text{Li}_{1.5}\text{Al}_{0.5}\text{Ge}_{1.5}(\text{PO}_4)_3$  (LAGP), and  $\text{Li}_{1.3}\text{Al}_{0.3}\text{Ti}_{1.7}(\text{PO}_4)_3$  (LTP) [6]. The authors determine that the thermal conductivity is  $0.470 \pm 0.009 \text{ WK}^{-1} \text{ m}^{-1}$ ,  $0.5 \pm 0.2 \text{ WK}^{-1} \text{ m}^{-1}$  and  $0.49 \pm 0.02 \text{ WK}^{-1} \text{ m}^{-1}$  for LLZO, LAGP, and LTP respectively, where the thermal conductivity of these SSEs is higher than for electrolyte-soaked separators.

### 3. Conclusions

The contents and topics of this Special Edition are extremely relevant to modern society, which needs an energy transition to a more sustainable but still high-performance model, lithium-ion batteries playing a key role in this transition. Continued efforts are needed to develop advanced smart and functional materials for electrodes and separators/solid polymer electrolytes to support the application requirements of LIBs as an alternative to commonly used materials and/or address their current limitations. These new advanced materials must be based on sustainable approaches, either in materials and/or processes, with reduced ecological footprint and high performance.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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