2025 Helmholtz – OCPC – Programme

for the involvement of postdocs in bilateral collaboration projects

PART A

Title of the project:

Polymer-Based Solid and Quasi-Solid-State energy storage systems

Helmholtz Centre and/or institute:

Helmholtz-Zentrum Berlin für Materialien und Energie (HZB)

Project leader:

Prof. Dr. Yan Lu

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Department: (at the Helmholtz centre or Institute)

Institute of Electrochemical Energy Storage

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Description of the project (max. 1 page)**:**

The next generation of energy storage systems requires both high energy density and enhanced safety. Compared to conventional liquid electrolyte-based systems, solid-state and quasi-solid-state lithium-ion batteries (SSBs and QSSEs) exhibit superior thermodynamic and chemical stability, along with the potential to accommodate lithium metal anodes. These advantages make them strong candidates for future energy storage applications.

Polymer-based materials offer distinct advantages over inorganic materials, including lower design and synthesis costs, superior electrode-electrolyte interfacial compatibility, and broader applicability (ranging from solid-state to quasi-solid-state systems, and from electrode binders to electrolyte materials). Although some polymer-based quasi-solid-state battery systems are approaching commercial application, there are still several critical challenges for polymer based solid/semi-solid batteries, such as Low ionic conductivity in the solid state electrolyte at low temperatures, limited lithium-ion transport efficiency within cathode materials in solid and quasi-solid-state systems, and unstable interface between lithium anode and electrolyte at high current, which prevent it from realizing theoretical advantages over liquid-state lithium-ion battery systems.

Thus, this project aims to optimize polymer structures and design strategies based on lithium-ion conduction mechanisms to improve the overall performance of polymer-based SSBs and QSSEs. The solid-state quasi-solid-state energy storage systems studied include polymer lithium-ion batteries, lithium-sulfur batteries, all-organic quasi-solid-state lithium-ion batteries, etc. The key focus areas include but not limited to:

1. High-Performance Polymer Cathode Binders
 - Develop an integrated design that combines ion conductors with binders, enabling efficient electronic and lithium-ion transport within cathodes without the need for liquid additives.
 - Introduce special functional groups in the polymer binder structures to suppress polysulfide dissolution, enhancing the cycling stability of sulfide-based cathodes.

2. Polymer-Based Solid and Quasi-Solid Electrolyte Films
 - Explore lithium-ion conduction mechanisms within polymer based solid/quasi-solid electrolyte through a combination of laboratory existing in situ and ex situ characterization techniques (e.g. scattering methods, Raman spectroscopy, X-ray photoelectron spectroscopy, cryo-EM, etc.).
 - Based on the understanding of lithium ion transfer behavior, rationally design polymer structures and optimize membrane composition to fabricate high-performance solid and quasi-solid-state electrolyte films.

3. Artificial SEI Layers via Polymer Frameworks
 - Utilize polymer frameworks, either independently or in combination with inorganic nanomaterials, to construct stable artificial SEI layers on lithium metal surfaces.
 - Suppress lithium dendrite growth while improving electrolyte-lithium metal interfacial compatibility.

Description of existing or sought Chinese collaboration partner institute (max. half page)**:**

The project leader has already established collaboration with multiple research institutions in China. The project leader has close collaboration with Prof. Guosong Chen at Department of Macromolecular Science, Fudan University, a world-leading research group on self-assembly of functional macromolecules. We have been successfully granted a joint DFG-NSFC project (2019-2023) and a Sino-German Joint Research Project (2015-2017) on exploring the mechanism of morphological transitions of macromolecular self-assemblies. In the last five years, we have published more than 15 papers in leading journals, including J. Am. Chem. Soc., Angew Chem. Int. Ed. and ACS Nano. Within the framework of the HGF-OCPC Programme, the project leader has successfully hosted three postdocs. The program has achieved fruitful outcome and established close collaboration with Prof. Hong Meng from Peking University (Shenzhen College).

Required qualification of the postdoc:

- PhD in Material Science or Polymer Science
- Experience with polymer-based solid electrolyte and/or nanomaterials synthesis
- Additional skills in materials characterization methods and electrochemical testing
- Language requirement: A good command of English (spoken and written) is required